DISINFECTION OF WATER AND WASTEWATER

Water is considered to be essential for all life. Approximately two-thirds of the human body is made of water. As part of our daily living, water is taken from the environment, treated and consumed by individuals. In most populated areas, domestic wastewater is treated and then returned to the environment. In either case, the quality of water and wastewater is essential to maintain public health. Since development of the "germ theory" of disease by Louis Pasteur in the late 1880's, the quality of our water supply has become more and more important. Federal regulation of drinking water began in 1914. The Federal Water Pollution Control Act in 1972 brought to focus regulations on wastewater treatment and the quality of effluent discharged to the environment. All of this effort has paid off. In February 2000, the National Academy of Engineering ranked improvements in our water supply, including disinfection with chlorine, among the greatest achievements in public health of the 20th Century. While a variety of technological advancements have virtually eliminated the spread of waterborne disease, the disinfection of water and wastewater continues to be one of the most important tools for maintaining the current quality of our water supply and for the protection of public health.

GENERAL

The disinfection of potable water and wastewater provides a degree of protection from contact with pathogenic organisms including those causing cholera, polio, typhoid, hepatitis and a number of other bacterial, viral and parasitic diseases. Disinfection is a process where a significant percentage of pathogenic organisms are killed or controlled. As an individual pathogenic organism can be difficult to detect in a large volume of water or wastewater, disinfection efficacy is most often measured using "indicator organisms" that coexist in high quantities where pathogens are present. The most common indicator organism used in the evaluation of drinking water is Total Coliform (TC), unless there is a reason to focus on a specific pathogen. The most common indicator organism for wastewater evaluation is fecal coliform but there has been discussion regarding the use of *Escherichia coli* (E. coli) or Total Coliform. As domestic wastewater contains approximately 1,000 times more indicator organisms than typical surface water, understanding wastewater disinfection will make it easier to understand water disinfection.

DISINFECTION OF WASTEWATER

There are a number of chemicals and processes that will disinfect wastewater, but none are universally applicable. Most septic tanks discharge into various types of subsurface wastewater infiltration systems (SWIS), such as tile fields or leach fields. These applications rely on the formation of a biomat at the gravel-soil interface where "biodegradation and filtration combine to limit the travel of pathogens."[1] Aerobic treatment processes reduce pathogens, but not enough to qualify as a disinfection process. "Chlorination/dechlorination has been the most widely used disinfection technology in the U.S.; ozonation and UV light are emerging technologies."[2] Each of these three methods have different considerations for the disinfection of wastewater.

Ozone

Ozone (chemical symbol O_3) is technically a triatomic allotrope of oxygen. In simpler terms, one molecule of ozone is made up of three atoms of oxygen. (With most oxygen occurring in nature, one molecule of oxygen is made up of two atoms of oxygen.) Ozone occurs occasionally in nature but is also electromechanically manufactured and used as a disinfectant. Ozone gas is extremely unstable. Liquid ozone and air-ozone mixtures will readily explode, therefore, ozone needs to be generated onsite rather than at a central facility and transported.

When dissolved in wastewater, ozone may directly oxidize organic substances, or combine with other substances to make compounds which have some disinfecting properties. As with most chemicals, the disinfection efficacy of ozone is influenced by a number of factors including the ozone dose, the contact time, the quantity of suspended solids in the wastewater, the pH of the wastewater, the chemical oxygen demand in the wastewater, the organic carbon present in the wastewater, the temperature of the wastewater and the design of the downstream contact tank. Ozone has also been found to be effective on protozoa including the cysts of *Giardia* and *Cryptosporidium*.

Ozone is impractical for many wastewater treatment plants. Because of the lack of stability, ozone generators must be placed at the treatment plant site. Many ozone generators are complex electrical devices that are maintenance intensive. In addition to the gas generating apparatus, there needs to be a method for dissolving the gas into the liquid, as well as a mixing and contact tank. Any ozone gas that is not retained in the wastewater must be destroyed before the contact tank can be vented to the atmosphere, as ozone gas is irritating to humans and may be toxic.

Ultraviolet Light

There are a number of considerations to disinfecting wastewater by irradiation with ultraviolet (UV) light. Ultraviolet irradiation achieves disinfection by inducing photobiochemical changes within microorganisms. The radiation does not directly kill the organisms, but "penetrates the genetic material of microorganisms and retards their ability to reproduce."[3] In most UV systems, treated effluent is directed through an open channel containing an arrangement of low or medium pressure mercury arc lamps generating invisible UV light at a wavelength of 250-270 nanometers. At this wavelength, the light disrupts the genetic material of the microorganisms. Proper disinfection requires that sufficient lamps be installed to expose all of the effluent to the radiation for a sufficient contact time as the wastewater passes through the channel. A consistent, controlled, laminar flow is required in order to insure that proper disinfection takes place. Also, the water must be free from suspended material and light-absorbing substances. "Since effective disinfection is dependent on wastewater quality as measured by turbidity, it is important that pretreatment provide a high degree of suspended and colloidal solids removal."[4]

UV lamps require electrical energy for operation. Each submerged lamp is traditionally protected by a quartz sleeve to allow transmission of the light energy into the effluent while maintaining watertight integrity. Over time, the various compounds present in wastewater form a film over the quartz sleeve. This accumulated film will inhibit the transmission of light energy and will negatively impact the disinfection process. To monitor disinfection efficacy, a UV intensity meter is usually mounted a short distance from one of the lamps in order to indicate when the quartz sleeve has fouled or the effluent has sufficient suspended solids to block the UV light transmission.

Maintenance of the lamps needs to be done at least four times per year in order to provide continuous disinfection. Manual maintenance involves removing of the lamps and hand cleaning of the quartz sleeves. Chemical maintenance requires the flow stream to bypass the unit while the entire channel and lamp module is filled with a chemical cleaning solution to remove the accumulated film.

UV systems have grown in popularity. As the generation of light is automatic and does not depend on the periodic addition of chemicals, ultraviolet light systems seem like a good option for disinfecting wastewater. However, the high capital cost combined with the frequent monitoring and maintenance requirements make the use of UV prohibitive. Additionally, the lack of a disinfectant residual can negatively impact the quality of the downstream effluent. "The kinetics of disinfection are also complicated by the fact that disinfectant-injured organisms, through repair mechanisms, can reactivate to a limited extent both in light and dark. This reactivation, sometimes referred to as regrowth, is mostly reported in the case of UV disinfection."[2]

Chlorination

"The history of wastewater disinfection is essentially the history of chlorination, and the use of chlorine has generally been associated with the search for means to control disease in man."[5] Chlorine is the most widely used of a family of halogens like bromine and iodine that have the capacity to disinfect water. Chlorine occurs in nature, but only in combination with other elements or compounds. Chlorine gas, sodium hypochlorite solutions and calcium hypochlorite are all suitable oxidizing materials for wastewater disinfection, but each has different considerations. With all three forms of chlorine disinfection, mixing of the applied chlorine with the effluent occurs at the contact tank. The combination of the chlorine dose and contact time has been proven to be an extremely effective disinfectant.

Chlorine gas (chemical symbol Cl_2) is usually applied directly when large quantities of chlorine are required. Normally, compressed chlorine gas is delivered in steel cylinders from 15 pounds up to 90-ton railroad cars. Mechanical devices dissolve the chlorine gas into potable water or effluent to make a chlorine solution, which is then applied to the flow stream as it enters the contact tank. Because of the extreme volatility and hazardous nature of chlorine gas, stringent safety precautions must be exercised during all phases of chlorine shipment, storage and use.

Chlorine gas is rated as "Extremely Hazardous" material by the Department of Transportation. Transportation of greater than 1,000 pounds requires specially licensed drivers following designated routes that have been prescribed by the local fire department. Operators working with chlorine gas must work on the buddy system. High quantities stored on site require siren alarms and evacuation plans filed with the local Emergency Management Agency.

Sodium hypochlorite (chemical symbol NaOCl) is a hazardous and corrosive material but is considerably more stable and easier to use than compressed chlorine gas. The primary advantage of hypochlorination over chlorine gas is the increased safety in transporting, storing and handling of the chemical, although the raw material cost is generally higher than gas chlorine. Also, the shelf life of sodium hypochlorite is shorter than the shelf life of other chlorine compounds. Sodium hypochlorite typically contains between 5.25% available chlorine (household bleach) and 15% available chlorine (commercial strength). For most applications, sodium hypochlorite is fed into the effluent stream via a controlled, metering pump. It is then thoroughly mixed with the effluent as it enters the contact tank.

MANUFACTURED BY
norweco®
Engineering the future of water and wastewater treatment
NORWECO, INC.
NORWALK, OHIO
U.S.A. 44857
www.norweco.com

Calcium hypochlorite (chemical symbol $Ca(OCl)_2$) utilizes chlorine in its dry form. Commercially available tablets containing 65% or 70% available chlorine can be added to an erosion type tablet feeder for dissolution into water or wastewater. In most applications, the tablet feeder is connected in line with the effluent stream and requires no additional make up water. The flow stream dissolves the dry chlorine tablets as the liquid passes through the tablet feeder. As with other oxidizers, the chlorinated liquid is mixed and retained in a downstream contact tank for adequate time to allow disinfection to occur. Calcium hypochlorite tablets are by far the safest and most economical chlorine product used to disinfect wastewater.

Because the chlorine tablets are dissolved directly into the water, no electricity or other energy source is utilized in the disinfection process. Operation of the tablet chlorinator is automatic and dependent only on the wastewater flow. The supply of tablets is stored in one or more feed tubes, the bottom of which is contained in the effluent flow stream. As the lowest tablet dissolves, applying a controlled amount of chlorine to the effluent, the remaining tablets automatically drop down providing continuous operation. Various process controls can adjust the chlorine delivery rate, depending on the effluent hydraulic and chemical characteristics and disinfection requirements.

Calcium hypochlorite tablets are usually packaged in DOT approved plastic containers that can be easily shipped via commercial carrier or package service. As with other forms of chlorine, safe handling, storage and application requires reasonable safety precautions. However, the equipment required for handling chlorine tablets is usually limited to personal safety items like rubber gloves and goggles. Routine maintenance consists of periodically refilling the feed tubes and can typically be done by persons with limited training following general safety precautions. Storage of the tablets in a cool dry place away from petroleum and organic products is usually sufficient to prevent any undesirable reactions from occurring. Specific safety precautions and instructions for use are provided on each product label.

Tricholorisocyanuric acid (chemical symbol $Cl_3(NCO)_3$) can be manufactured into tablets that dissolve slowly in swimming pools, but can be dangerous if used for wastewater disinfection. The slow dissolve rate results in a low chlorine dose and additional monitoring is required to be sure that sufficient pathogen kill is taking place. Also, because they are chemically unstable, mixing “trichlors” with other chlorine disinfection products will cause chemical reactions ranging from the liberation of chlorine gas, to a self-sustaining fire, all the way to a full explosion. Additionally, extreme caution must be exercised when any trichlor product is allowed to be partially submerged or placed in a damp location, such as in an erosion type tablet feeder. In this application, trichlor products will decompose and produce nitrogen trichloride gas (chemical symbol NCl_3), which is highly explosive as it accumulates in an enclosed feeder.

Oxidant Demand

Although oxidants such as ozone and chlorine are added to wastewater effluents for the purposes of disinfection, ancillary chemical reactions between the oxidizers and various compounds in wastewater can play a factor in disinfection efficacy. The widely used term “chlorine demand” is sometimes misused or at least misunderstood. In simplest terms, the chlorine demand is the difference between the chlorine applied and the residual concentration after a specific contact time and at a prescribed temperature and pH.

With regards to the disinfection of wastewater effluents, there has been a lack of continuity within the industry. Some references have defined chlorine demand as the amount of chlorine that needs to be applied to an effluent in order to achieve a specific coliform concentration prior to discharge. Other references consider only the amount of chlorine required to satisfy the combining of chlorine with other compounds (often ammonia) that occurs before the formation of a free chlorine residual. “Standard Methods”[6] Section 2350, (approved 1997) Oxidant Demand/Requirement, outlines the laboratory procedures for calculating the chlorine demand or the ozone demand of a specific wastewater flow stream.

The degree of treatment of the wastewater prior to disinfection is a significant factor in the chlorine demand. As some of the more common compounds that occur in chlorinated wastewater, like hypochlorous acid or chloramines, have varying degrees of disinfection efficiency, it is a complex process to predict the final concentration of indicator organisms without field testing.

Most domestic wastewater contains significant quantities of organic nitrogen. Septic tanks, and other anaerobic treatment processes do little or nothing to stabilize nitrogen compounds. If the wastewater is retained in a collection system, or in a septic tank for several hours, a high percentage of the organic nitrogen undergoes the “ammonification” process whereby it is converted to ammonia-nitrogen. Chlorine readily combines with ammonia to form chloramines in wastewater effluent from anaerobic processes. While chloramines do have disinfectant properties, they are significantly less efficient than a free chlorine residual. Applying chlorine to an effluent containing ammonia results in a higher chlorine demand and more chemical is needed to meet a specific permit limit.

Conversely, many aerobic treatment processes, especially extended aeration processes, have sufficient detention time and adequate available oxygen to convert ammonia to nitrate through a biological process called nitrification. As the ammonia has already been oxidized, the addition of a small dose of chlorine to the nitrified effluent produces a free chlorine residual and disinfection is readily accomplished. As aerobic treatment units typically discharge higher quality effluent than anaerobic processes, there is less chlorine demand and disinfection requirements are more easily achieved.

Effluent Quality

Ozone does not produce an effluent residual. Initially, this may seem like an advantage as no further treatment to remove a residual is required. However, without a residual, there is no way to monitor the efficiency of the process without conducting frequent sampling and laboratory testing for indicator organisms. Also, unless a total bacterial kill is accomplished, the regrowth of microorganisms can occur immediately downstream of the contact tank.

Ultraviolet irradiation also does not produce an effluent residual. Therefore, if complete disinfection does not occur at the point of contact with the lamps, there is nothing to control pathogens the instant the flow moves downstream of the UV unit. A slug discharge of suspended solids, a low UV dose due to partially fouled tubes, or even a power failure can result in the discharge of pathogenic organisms. Similar to ozone, as there is no effluent residual, the disinfection efficiency of ultraviolet irradiation cannot be determined without bacterial sampling and testing on a frequent basis.

Chlorination is the only commonly used disinfection process that produces an effluent residual. Residual chlorine in the effluent is a positive indicator that the chlorine demand has been satisfied. Additionally, it serves several other important purposes. As disinfection efficacy is largely a factor of free available chlorine (FAC) and contact time, the reduction of pathogens can be reasonably indicated by a simple test or continuous effluent chlorine monitoring. A chlorine residual in the effluent also provides extended control over the regrowth of pathogenic organisms in the effluent stream. With any type of disinfection process, particulates in the effluent stream can protect pathogenic organisms from destruction and later release pathogens as the particulates mechanically or biochemically degrade. An effluent chlorine residual can provide enhanced disinfection process control, right up to the point of discharge.

Dechlorination is sometimes used to remove chlorine from the effluent prior to discharge to the environment. Removal of the free and combined chlorine is generally required if the treatment plant is discharging to environmentally sensitive surface waters. If the removal of residual chlorine is desired, "dechlorination can virtually eliminate toxic effects resulting from wastewater chlorination."[2]

Dechlorination is most readily accomplished by the addition of a reducing agent, usually sodium sulfite (chemical symbol Na_2SO_3). A popular method for applying a dechlorination agent is with the use of sodium sulfite tablets applied in the exact same manner as chlorine tablets. A tablet feeder connected in line with the effluent of the chlorine contact tank will chemically neutralize both free and combined chlorine. An additional contact tank is not required, as the reduction of the chlorine by sodium sulfite is nearly instantaneous. In this way, the disinfected and dechlorinated effluent can be readily returned to the environment.

Effluent Sampling

Sampling and testing of system effluent is required to determine disinfection efficacy or compliance with permit limits. Wastewater disinfectants are registered with the USEPA and are labeled with specific instructions on approved laboratory test procedures. Lab testing must be performed on effluent samples that have been collected, stored and transported following proper procedures. Composite samples are not suitable for coliform testing. A grab sample of effluent must be collected into a sterile container, being careful to avoid any contamination. If the effluent has been disinfected using chlorine, at the time of collection, 0.008% of sodium thiosulfate (chemical symbol $Na_2S_2O_3$) must be added to neutralize any chlorine residual and prevent further disinfection during sample storage and transport. The sample must be cooled to $4^{\circ}C$ to prevent regrowth from occurring following neutralization. In any case, the sample should be analyzed in the laboratory within six hours of collection.

DISINFECTION OF WATER

Disinfection is usually the final stage in the water treatment process in order to limit the effects of organic material, suspended solids and other contaminants. Like the disinfection of wastewater, the primary methods used for the disinfection of water in very small (25-500 people) and small (501-3,300 people) treatment systems are ozone, ultraviolet irradiation (UV) and chlorine. There are numerous alternative disinfection processes that have been less widely used in small and very small water treatment systems, including chlorine dioxide, potassium permanganate, chloramines and peroxone (ozone/hydrogen peroxide).

Surface waters have been the focal point of water disinfection regulations since their inception, as groundwaters (like wells) have been historically considered to be free of microbiological contamination. Current data indicates this to not be true. Amendments to the Safe Drinking Water Act in 1996 mandate the development of regulations to require disinfection of groundwater "as necessary." While these regulations will apply to very small systems serving twenty-five people at least 60 days out of the year, the rules will not apply to private wells. However, the EPA recommends that wells be tested at least once per year and disinfected as necessary. While these proposed regulations have not yet been finalized, they will likely include; testing by each state, identification of contaminated water supplies, corrective action requiring disinfection and compliance monitoring. The rules are currently scheduled to be implemented in July 2003.

MANUFACTURED BY

norweco®
Engineering the future of water and wastewater treatment

NORWECO, INC.
NORWALK, OHIO
U.S.A. 44857
www.norweco.com

Primary and Secondary Disinfection

The disinfection of potable water is usually done in two stages. Primary disinfection is used to initially reduce the concentration of microbial contaminants (pathogens and indicator organisms) to a level safe for human consumption. As this process does not necessarily mean complete sterilization, the potential regrowth of pathogens within a distribution system still exists. Secondary disinfection is designed to provide residual control of microorganisms throughout the distribution system and up to the point of use. A primary disinfectant might be ultraviolet irradiation (UV), ozone or one of the various forms of chlorine. However, secondary disinfection is limited to some form of chlorine compound. If ozone or UV is selected as a primary disinfectant, then chlorine compounds must be selected as a secondary disinfectant. On the other hand, chlorine compounds can be used as both primary and secondary disinfectants within the same treatment and distribution system. "Chlorine is, by far, the most commonly used disinfectant in the drinking water treatment industry."[7]

Disinfection By-Products

The disinfection of water has been wide-spread and growing since the early 1900's and is largely responsible for the virtual eradication of many waterborne diseases. However, disinfection by-products (DBPs) are formed when disinfecting chemicals combine with organic or inorganic compounds present in the water, resulting in new compounds that may have undesirable health effects when ingested. In 1974, researchers confirmed that trihalomethanes (THMs) are formed as a result of chlorine combining with natural organic matter (such as algae) in water. THMs have been shown to be carcinogens in laboratory tests with animals. While the connection to humans has not been proven, the potential to affect a large portion of the population means the risks must be taken seriously, especially since humans consume a large quantity of treated water over their lifetime.

As a result of the discovery of DBPs, including THMs, alternative disinfectants have been more heavily explored. "Some of these alternative disinfectants, however, have also been found to produce DBPs as a result of either reactions between disinfectants and compounds in the water or as a natural decay product of the disinfectant itself."[7]

Concern over DBPs must be kept in perspective. Considerable attention has been given to the study of THMs and precursors. So much attention that some organizations have "reminded" the industry of the immediate danger of compromising disinfection in order to respond to the "fear factor" associated with carcinogens. The American Water Works Association says "as other disinfection by-products (DBPs) were identified in treated drinking water, worries about potential health risks, especially cancer, that might be associated with disinfection have sometimes overshadowed the real threat of infectious waterborne diseases."[8]

Ozone

Ozone is highly reactive, capable of oxidizing microbes and many organic and inorganic compounds in water. This results in a high germicidal effectiveness against a wide range of pathogenic organisms including bacteria, protozoa and viruses. In addition to disinfection, ozone contributes positively towards color, taste and odor control in drinking water. However, ozone has limited applications as a disinfection agent for potable water, particularly for small or very small water treatment systems. The use of ozone is limited to being used as a primary disinfectant.

The process for using ozone as a water disinfectant is very similar to its use in wastewater. The complex mechanical equipment and operational requirements for ozone generating, disinfecting and safety equipment is usually beyond the scope of all but larger size treatment systems.

Disinfection with ozone does not result in halogenated disinfection by-products like THMs, but it does create numerous DBPs in the form of inorganic compounds, such as aldehydes, ketones and acids.

Ultraviolet Light

Ultraviolet irradiation (UV) is sometimes used to disinfect potable water in a method very similar to the disinfection of wastewater, but not all states allow the disinfection of private water supplies by UV. The equipment used for disinfection of water is similar to the equipment used for the disinfection of wastewater except the units are usually pressurized chambers versus open channels. The benefits are also similar in that daily operation is automatic as no chemicals are consumed or required for refill.

However, because of the direct effects on public health, the maintenance and operational aspects of UV systems are even more important. Pretreatment, including filtration to remove discoloration, turbidity and organic particles is commonly required. Water softeners or phosphate injection equipment may be required to prevent the premature fouling of the quartz sleeve. In any case, contamination of the sleeve will eventually occur and require mechanical or chemical cleaning. Because of the direct impact on health, a UV monitor should be used to guarantee proper light transmittance and absorbance.

"Based on the available research literature, it appears that although exceptional for disinfection of small microorganisms such as bacteria and viruses, UV doses required to inactivate larger protozoa such as *Giardia* and *Cryptosporidium* are several times higher than for bacteria and virus inactivation."[7]

There have been minimal DBPs measured as a result of UV disinfection of potable water supplies. Most of the changes occurring in the water as a result of ultraviolet irradiation do not appear to have negative health effects.

Chlorination

"**Chlorine** is the disinfectant of choice for drinking water for a number of reasons. Its wide range of benefits can not be provided by any other single disinfectant."[9] Chlorination is the most widely used process for water disinfection. Approximately 98% of all drinking water treatment systems use chlorine-based disinfectants for drinking water treatment. Small and very small water treatment systems generally use sodium hypochlorite or calcium hypochlorite for disinfection. Both of these products can be used as a primary or as a secondary disinfectant.

Sodium hypochlorite (NaOCl) is used to disinfect water in much the same manner as it is used to disinfect wastewater. An adjustable metering pump feeds the sodium hypochlorite from the solution tank directly into the drinking water supply system. Often times, activation of the chemical pump is triggered by an electrical control from the water supply pump, such as in a well. In the case of a private well, the pressure tank also serves as a contact chamber allowing sufficient time for disinfection to occur. Once the initial adjustment is achieved, refilling the solution tank and maintenance on the chemical feed pump are usually sufficient to maintain proper operation and disinfection.

Calcium hypochlorite ($Ca(OCl)_2$) is also suitable for water disinfection. There are two primary methods for using dry chlorine in small and very small water treatment systems.

Erosion type tablet feeders are widely used for the disinfection of drinking water. The primary difference in operation from a wastewater tablet feeder is the inline feeder for drinking water is usually a pressure type apparatus, versus a gravity flow unit. Several types of process controls can adjust the chlorine delivery rate into the water stream. Following the initial adjustment, refilling of the canister with tablets is the only routine maintenance required.

Pellet chlorinators are commonly used in water wells. Mounted on the well casing, small pellets of calcium hypochlorite are stored in the unit and metered into the well as required. Some units are designed to feed pellets according to an electrical signal from the well pump. Other units are designed to feed pellets on a time basis. In either case, the feed rate must be adjusted to allow for satisfaction of the chlorine demand and disinfection requirements.

Especially in the case of private wells, occasionally shock chlorination is used to disinfect mechanical equipment or the distribution system, even in wells that are not chlorinated regularly. Local health departments can provide detailed instructions and step by step procedures on this process.

SUMMARY

The last 100 years have brought significant environmental advances. At the beginning of the 20th Century, water and wastewater were treated by one principle, "the solution to pollution is dilution." But as population density increased, so did the spread of infectious disease. Only by the use of science and technology have we been able to identify threats to public health and find ways to overcome them.

Driven partly by regulation, safe drinking water has now become commonplace. Ongoing research will continue to make it more safe, even in the light of increasing wastewater reuse. Wastewater effluent limits also continue to evolve. "Attainment of the disinfection guidelines can only be achieved by the disinfection process, which, from a disease prevention standpoint, is the most important unit process in the wastewater treatment system."[10]

Disinfection of water and wastewater, primarily by chlorine, has played a large part in the reduction of waterborne diseases. While new disinfection processes are constantly being developed, the industry cannot abandon proven technology. This is of such importance that The Wall Street Journal cited U.S. Army Chemical Engineer, David A. Reed as saying "until alternative technologies are more widely accepted, the country can't do without chlorine."[11]

REFERENCES

1. National Small Flows Clearinghouse, Small Flows Quarterly. (Fall 2001). *The Role of Biomats in Wastewater Treatment*.
2. Water Environment Federation. (1996). *Wastewater Disinfection Manual of Practice FD-10.*
3. National Small Flows Clearinghouse. (1998). *Ultraviolet Disinfection*, *A Technical Overview.*
4. U.S. Environmental Protection Agency. (2002). *Onsite Wastewater Treatment Systems Manual*.
5. Geo. Clifford White. (1978). *Disinfection of Wastewater and Water for Reuse.*
6. American Public Health Association, American Water Works Association, Water Environment Federation. *Standard Methods for the Examination of Water and Wastewater.* 20th Ed.
7. U.S. Environmental Protection Agency. (1999). *Alternative Disinfectants and Oxidants*.
8. American Water Works Association Journal. (September 1997).
9. Water World. (September 1998). *The History of Chlorine.*
10. U.S. Environmental Protection Agency. (1986). *Municipal Wastewater Disinfection Design Manual*.
11. Ann Davis, The Wall Street Journal. (May 30, 2002). *New Fears Heat Up Debate on Chemical Risks.*