Ozone, an Effective and Affordable Choice for Small Water Systems

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Abstract

Ozone, the strongest oxidant and disinfectant in commercial use has been employed in over 3,000 large scale municipal plants world-wide. In August 1997, and again in August 1998, the U.S. EPA identified ozone as a Small System Compliance Technology for existing National Primary Drinking Water Regulations related to revisions in the 1996 Safe Drinking Water Act.

Survey data developed to support the inclusion of ozone as a "Compliance Technology" identified that over half of the more than 260 U.S. municipal ozone installations known to be operating in early 1998 are in systems treating less than 1 MGD (e.g., plants that serve less than 10,000 persons). An additional 363 community, non-community and single family ozone installations using a novel ozone (based on ultraviolet generation) and filtration process also were identified.

In this paper, the authors explore the data from this on-going U.S. survey to explain how ozone can be used safely and effectively in small systems applications. Special detail is paid to the simplification of otherwise rather complex requirements of engineered subsystems, e.g., the ozone generator, feed gas treatment, power supply, gas/liquid contacting, and contactor off-gas destruction. Design of small ozonation systems, performance, capital and operating costs will be presented, along with a discussion of some basic aspects of ozone technology in combination with filtration systems.

Ozone Treatment of Potable Water

Ozonation has been in continuous use in Nice, France since 1906, to ensure disinfection of a mountain stream water. Since ozone was first installed in Nice, there is today an estimated 3,000 other potable water treatment plants using ozone throughout the world. Because ozone is both the strongest oxidant and strongest disinfectant available for potable water treatment, this unique material can be utilized for a number of specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, H_2S removal, nitrite and cyanide destruction, oxidation of many organics (e.g., phenols, some pesticides, some detergents), algae destruction and removal, and as a coagulant aid.

Even though ozone is the strongest chemical disinfectant available for water treatment, there are some refractory organics that it will not oxidize, or will oxidize too slowly to be of practical significance. In such cases, ozone can be combined with UV radiation and/or hydrogen peroxide to produce the hydroxyl free radical, HO•, which is an even stronger oxidant than is molecular ozone, O_3. Deliberate production of the hydroxyl free radical starting with ozone has been termed "Ozone Advanced Oxidation". Some groundwaters that are contaminated with chlorinated organic solvents and some refractory hydrocarbons are being treated successfully by ozone advanced oxidation techniques.

Properties and Generation of Ozone

At ambient temperatures, ozone is an unstable gas, partially soluble in water (generally more soluble than oxygen). Due to its instability (it quickly reverts to oxygen), ozone cannot be produced at a central manufacturing site, bottled, shipped and stored prior to use. It must be generated and applied on-site, as it is required. This means the installation of an ozone production plant at its point of use – which for small systems can be inside or outside of an individual home.

Ozone is generated for commercial uses either by corona discharge or by ultraviolet radiation. By the UV technique, rather low concentrations of ozone (below 0.1 wt %) are generated, whereas by corona discharge, ozone concentrations in the range of 1-4.5 wt % are produced when dry air is fed to the ozone generator. When concentrated oxygen is used as the feed gas, gas phase ozone concentrations of up to 14 to 18% (by wt) can be produced on commercial scale.

Since ozone is only partially soluble in water, once it has been generated it now must be contacted with water to be treated in such a manner as to maximize the transfer of ozone from the gas phase into water. For this purpose, many types of ozone contactors have been developed; all of which are effective for their designed water treatment purposes. However, as higher concentration ozone gas is employed, contacting system design becomes more critical due to the lower gas to liquid ratios. Also, the use of oxygen as the feed gas can result in oxygen super saturation of the treated water causing both operational problems in following treatment processes and aesthetic in the distribution system.

Ozone contacting system options include atmospheric tall tower or pressurized gas to liquid mass transfer processes. Fine bubble diffusers, static mixers or venturi injectors can be used to mix the gas with the water to be treated in either full flow or sidestream configurations. In many small systems, small in-line injectors and pressurized reaction vessels and of gas removal systems replace the huge concrete, 20-ft deep bubble diffuser tanks which are cost-effective on large scale.

Once dissolved in water, ozone now is available to act upon water contaminants to accomplish its intended purposes of disinfection and/or oxidation. At low pH levels (3-6, for example) the ozone is present primarily in its molecular form (O_3). However, as the pH rises, the decomposition of ozone to produce the hydroxyl free radical (HO•) becomes increasingly rapid. At pH 7 about 50% of the ozone transferred into water produces HO•. At pH > 10, the conversion of molecular O_3 to HO• is virtually instantaneous.

Fundamental aspects of ozone technology are well described in a number of exemplary publications (Rice and Netzer, 1982; Hoigné, 1988; Hoigné, 1998; Langlais et al., 1991), to which the reader is referred for additional details.

Engineering Aspects of Ozonation Systems

Because ozone is such a powerful oxidant/disinfectant, the trick to applying it to solve water treatment problems is to do so in a manner that is effective for water treatment, yet at the same time ensuring the safety of people in the vicinity. Ozone safety issues are handled quite easily by use of proper ambient ozone monitoring, tank venting and ozone destruction. It is a similar application engineering problem to applying gaseous chlorine for water treatment, to which must be added the idiosyncrasies of ozone.

Figure 1 shows the five basic components of an ozonation systems, ***all*** of which must be taken into account when designing/installing ozone to ensure effectiveness and safety simultaneously. Central to the ozonation system is the ozone generator itself, which in turn is connected to an appropriate power supply. For small-scale usage, the power supply can be a household wall plug.

For corona discharge ozone generation, it is critical to feed the generator a clean and dry oxygen-containing gas. Moisture in the feed gas causes two operating problems. First, the amount of ozone produced by application of a given electrical energy level is lowered as relative humidity rises. Consequently, it is usually cost-effective to dry the air to a recommended dew point of minus 65°C (-65°C = -76°F) or lower (Dimitriou, 1990). Second, when ozone is generated using air in the presence of moisture, the small amount of nitrogen oxides react with the moisture to produce nitric acid. Moist gas condensation at the cooling/heat transfer surfaces produces the corrosive compound which can soon cause corrosion problems in the ozone generation equipment, with concomitant increases in equipment maintenance requirements. Because of the high oxidative qualities of gas-phase ozone and the chance of moisture from a failing feed gas unit, small system managers should take extra care to make certain that all components in the ozone generator, ozone supply line, ozone gas to liquid mass transfer equipment and the contact vessel are ozone-compatible. Small system managers are encouraged to insist on proof of such compatibility from any ozone equipment manufacturer or vendor.

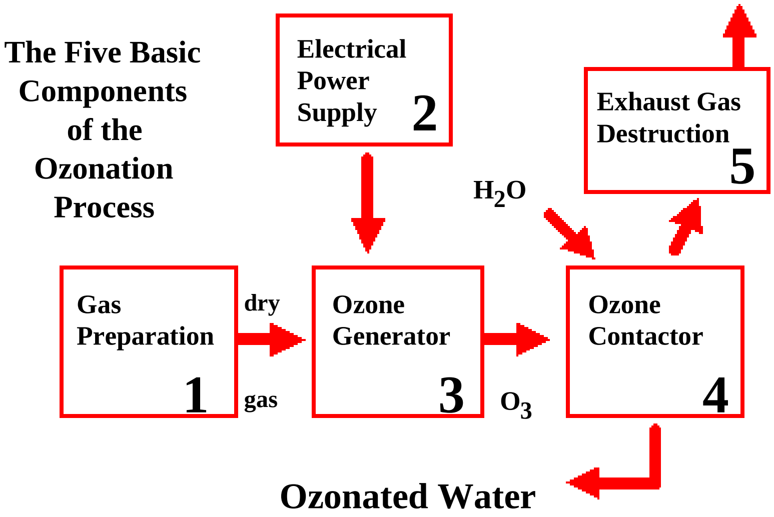

Figure 1. The five basic aspects of an ozonation system.

When ozone is generated by UV radiation, it is customary, particularly for small systems, not to dry the air. This is because the lower applied UV energy (compared to corona discharge) does not result in the formation of nitrogen oxides.

For large scale ozonation systems, the equipment for cleaning and drying feed gases can become quite complex. For example, effective air drying can involve the multiple treatment steps of air filtration, compression, cooling, desiccation, and final filtration prior to passage into an operating corona discharge ozone generator. For small community systems, several commercial-grade air dryers and small oxygen generators are available, but these must be matched carefully to the specifications of the ozone generator

The need for efficient ozone contacting has been discussed earlier, and the final necessity is a unit for destruction of excess ozone always present in contactor off-gases when generated by corona discharge. Absent an effective ozone off-gas destruct unit, this excess ozone would be present for people in the vicinity to breathe, which is not recommended due to its strong oxidizing nature. Additionally, ozone is heavier than ambient air, can settle in the vicinity, and can attack oxidizable materials. Destruction of contactor off-gas ozone is readily accomplished thermally (370°C), catalytically, thermal-catalytically, or (***only*** for small air-fed systems containing very low ozone concentrations) by passage through granular activated carbon. Care should be exercised in selecting an ozone destruct method whenever very high concentrations of ozone will be encountered because of the risk of heat generation and fire hazard.

To the five-component system shown in Figure 1 can be added instrumentation and controls for ensuring the effective and safe operation of the total system. And now the concern for applying ozone to small water treatment systems becomes one of how to miniaturize the tried and true large scale units to be effective and affordable systems for treating water in small systems. Aside from simply making each of the five components smaller in physical size, there are some additional techniques for corner-cutting without sacrificing quality in terms of production of ozone at desirable gas-phase concentrations. For electrical power, the home or business wall plug providing 110-V or 220-V single phase power replaces 3-phase supplies at 230, 460 or 575-V required at large installations. For air drying, desiccation or oxygen concentration is appropriate as the sole feed gas approach on small scale, replacing the multiple-treatments required at larger installations. For contacting, small in-line injectors replace the huge concrete, 20-ft deep bubble diffusers, which are cost-effective on large scale. In many small applications with extended storage capacity for prolonged ozone addition, UV generation of ozone can be practical for oxidation of iron and manganese, whereas UV generation at large water treatment plants is prohibitively higher in cost than corona discharge. Oxygen concentrators often replace air desiccation units to feed oxygen-enriched air to the ozone generators, thus producing higher gas phase ozone concentrations and increased output (g/h) per unit size on small scale, thus avoiding the need for on-site oxygen production and/or storage facilities.

In the opinion of the authors, a few reputable suppliers have accomplished miniaturization of small ozonation systems quite successfully, which include high-quality small oxygen concentrators. Some, however, have nearly destroyed the business by manufacturing some shoddy ozone generators and ozonation systems, resulting from inappropriate designs, improper materials of construction, and poor ancillary equipment. In addition to feed gas preparation and electrical power demands making the small equipment suitable for small communities, where slight environmental variations of ozone output are tolerable, air-cooled equipment can simplify installation and operation of the ozone treatment system.

These differences between ozone applied in small plants as opposed to large plants will be expanded upon in specific examples of installations to be described in later sections of this paper.

Additional details on the engineering aspects of ozonation systems can be found in an International Ozone Association Guidance Manual (Dimitriou, 1990). In late 1997, the Water Quality Association published *Ozone - A Reference Manual* (WQA, 1998), which provides guidance on ozone systems designed for point-of-use, point-of-entry, and small water treatment applications.

Industry-wide standards for ozone equipment are being developed. Until these are in place and widely adopted, buyers should use caution when purchasing any ozone production equipment. One should insist on and personally check with references and require any ozone generator manufacturer to provide certification of ozone output and concentration as well as warranty equipment performance.

Small Water Treatment Systems – Definitions

In the United States, the U.S. EPA has defined small water treatment systems as those serving fewer than 10,000 persons. This represents a maximum daily water production of about 1 million gallons (1 mgd). EPA further subcategorizes water plants into those serving fewer than 3,300 persons and serving fewer than 500 persons. From the standpoint of water treatment, the larger population category can be supplied with ozonation equipment, which is designed closer in concept to the larger size installations. However, when applied to systems serving fewer than 500 persons, including individual homes or even clusters of homes, it is important for ozone vendors to adopt methods by which the more costly large scale approaches can be avoided, while maintaining protection against exposure to gaseous ozone.

It is also important to recognize that the U.S. EPA regulates water systems down to those serving 25 or more persons, or systems with 15 or more service connections. Individual homes, or clusters of a few homes serving fewer persons or service connections, are not regulated by the EPA but may be regulated by the states. Washington State, for example, considers any installation of two or more homes (except for some farms) taking water from the same source to be a public water purveyor and subject to regulation. In addition, transient facilities, such as beds and breakfasts or camps and parks are regulated in the same manner as larger community systems, even if the operation involves only one building.

Operational U.S. Potable Water Plants Using Ozone

Figure 2 shows the rate of growth of ozone in U.S. water treatment plants since 1980 through April 1998. The first water treatment plant to utilize ozone continuously in the USA was installed in 1940 in Whiting, Indiana. In 1972, the second plant was installed in Strasburg, Pennsylvania. By 1980, only about 10 U.S. water treatment plants were known to be using ozone. However, thanks to the Safe Drinking Water Act Amendments of 1986 and subsequent events, interest in ozone treatment of drinking water in the USA began to climb. As of April 1998, some 264 water plants in the USA were known to be using ozone. In addition, one supplier of UV ozonation equipment has listed 363 residential units which have been identified by purchase of extended system/equipment warranties.

In Figure 3, the 264 operating water plants are broken down by size, in terms of mgd of water production. Of interest is the fact that 149 of these plants – well over half – produce less than 1 mgd (e.g., serve fewer than 10,000 persons). This fact alone makes it clear that

a. Ozone is not just for big water systems, and
b. Ozone must be affordable for small systems.

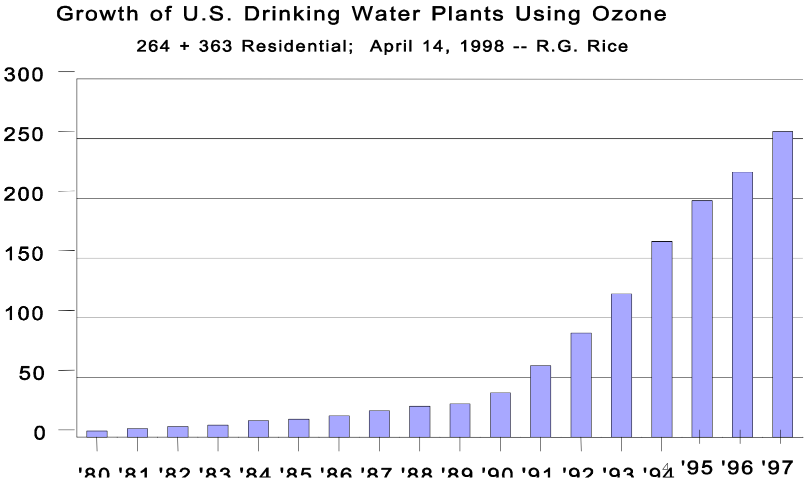

Figure 2. Growth of U.S. drinking water plants using ozone.

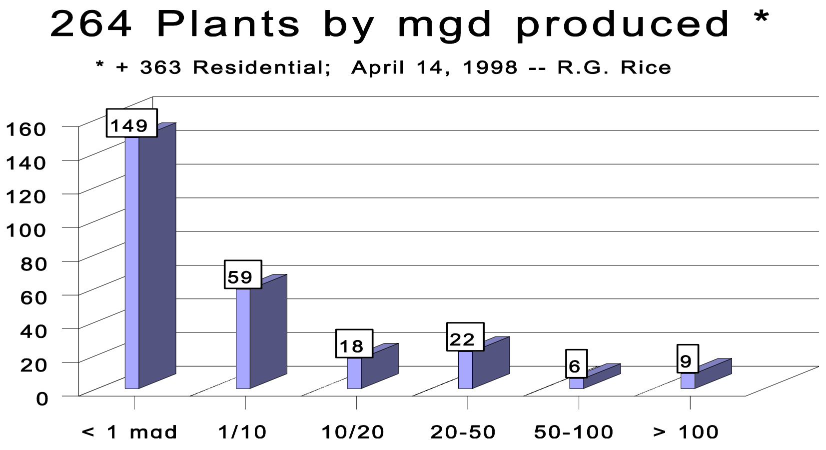

Figure 3. 264 ozone plants by MGD of water produced.

Ozone Applications in Small Water Systems

Since most of the plants using ozone are small, many are using ozone to treat groundwaters. In these instances, ozone is used primarily for disinfection (bacteria and viruses) and for oxidation of such typical groundwater contaminants as iron, manganese, sulfide and nitrite ions and sometimes color. Most of the much larger water plants using ozone treat surface waters and apply ozone for primary disinfection (*Cryptosporidium, Giardia* and virus inactivation), for oxidation of iron, manganese, taste and odor, color, for coagulation assistance, and for lowering levels of disinfection by-product (DBP) precursors. The current trend is for small community systems to use ozone for the same purposes as the larger plants.

With the promulgation of the Disinfectants/Disinfection Byproducts Rule (U.S. EPA, 1998a), EPA estimated that as many as 3,615 small surface water systems and 8,324 small ground water systems would be affected and that ozone was a potential treatment technology.

Because most small community systems rely on ground water, relatively few of the small plants use ozone to treat surface water sources, and have reported its installation to comply with the requirements of EPA's Surface Water Treatment Rule (SWTR). The vast majority use ozone either to treat groundwaters directly or to treat municipal tap water which is considered by the homeowner or small business owner to be of suspect quality, in spite of the fact that all applicable EPA drinking water standards are being met by the local utility.

Data Gathering From Small Water Systems

In contrast to the facileness of data gathering at large, municipally owned and operated water treatment plants, when attempting to extract similar data from small plants, the searcher encounters many difficulties. In the first place, simply trying to locate small water plants (using ozone) represents a major challenge. There are relatively few manufacturers/suppliers of large ozone equipment, and these are eager to participate in developing data for use by the entire industry. Whenever an order for ozone equipment is placed (usually through a company's representative), these large firms make that fact known in the form of press releases. Such press releases also contain considerable information concerning the plants themselves, including contact points for additional information.

Conversely, there are many more producers of small-scale ozone equipment, and most of these sell their equipment to distributors or dealers, who in turn sell directly to the consumer. Most purchasers of small-scale ozonation systems are private individuals or private water companies, as opposed to being publicly-owned municipal utilities. Private individuals and corporations have no incentive to provide information to questioners. Consequently, the manufacturer of small scale ozone equipment only knows how many systems he/she has sold to distributors/dealers during a given period, but not necessarily to whom the systems have been sold nor for which specific applications. As a result, a data gatherer must work with distributors and dealers (who usually are too busy trying to make additional sales to be bothered with the apparently non-productive exercise of developing statistical data), or, in rare cases, with private homeowners, when attempting to develop information about the performance and costs of specific ozone installations.

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Consequently, the totality of data assembled to date must be considered qualitative at best, and definitely on the low side when considering the total numbers of operational small ozone water systems. This is because the authors have received input only from a few suppliers of small ozonation systems. Since there are many suppliers of small ozonation systems, there must be many as yet unidentified installations. As an example, Figures 2 and 3 refer to 363 small ozone installations reported by only a single supplier – and these 363 systems were identified only as those that purchased an extended warranty policy. Thus, this one supplier has sold many times more than the 363 units counted by these authors. But since the actual number of small ozone systems installed by this one supplier is unknown, no attempt has been made to develop a "guesstimate" just to provide higher installation numbers.

A large percentage of small community water systems are organized as homeowner associations. As such, most do not have professional operators to manage their systems, nor do they have staff available to readily respond to questionnaires. A significant number of these associations are stressed for money and must seek outside funding for system treatment upgrades. Although these small systems report to the state and local regulators, typically they tend to react to regulations rather than planning ahead and initiating treatment until required to do so. In addition, many of the small associations tend to keep poor records, other than for regulated parameters, and management tends to change frequently as boards of directors are elected.

Data from some individual installations can be quite accurate in terms of installation and operating costs. It is another matter, however, to find installations that have anticipated future

EPA regulatory requirements and have developed analytical data for to-be-regulated water pollutants, such as trihalomethanes, haloacetic acids, bromate ion, etc. under the Disinfectants/Disinfection By Products (D/DBP) Rule of 1998 (U.S. EPA, 1998a).

Nevertheless, within the confines of these statements, information has been assembled for several case examples of small potable water treatment systems in the United States using ozone technologies. This information will be presented and discussed as much as possible in a similar format.

Ozone Education of Regulators

One of the most frustrating aspects to vendors of ozonation equipment is the lack of understanding (sometimes even the lack of interest in understanding) the various aspects of ozone technology by state and local water supply regulators. Usually these regulators have a firm grasp on chlorination and its application and analytical monitoring details. If ozone is new to such regulators, then the vendor of ozonation equipment is faced with having to educate these regulators of small water systems as to what ozone technology is all about. If the vendor of ozone equipment also is new to the technology and does not understand fully what he/she is marketing, the tendency is to over claim what ozone can do. Rarely can such over claims be supported by performance data, and under such circumstances there will be no quick approval of ozonation by the targeted regulators.

Faced with ozone technology for the first time, most State or local regulators will consider ozone simply to be a replacement for chlorine, and will initially require ozone to meet the same State or local standards as required for chlorine. In the past this has led to requirements for “cylinders of ozone to be stored.... “, which, of course, is a technological impossibility.

Once the basic ozonation system is understood along with its various applications for treating water supplies, the next educational step is to understand what pretreatment and what post-treatments may be necessary in order for ozone to perform its assigned task(s) most efficiently and cost-effectively. For example, if the raw water to be ozonized contains only hydrogen sulfide as the contaminant to be oxidized and disinfection is a second reason to use ozone, then all that is necessary to attain these dual objectives is to add ozone to the water. This is because the water-soluble sulfide ion (S^{2-}) will be converted during ozonation into the water-soluble sulfate ion (SO_4^{2-}). As long as sufficient ozone is added to such waters to convert all sulfide to sulfate ion -- eliminating the rotten egg odor in the process -- while allowing a residual of ozone to be attained, then disinfection of pathogenic bacteria (*E. coli*) can be assured.

On the other hand, if the raw water contains soluble iron and manganese, then ozone addition will convert these water-soluble materials into water-insoluble iron/manganese hydroxides or oxides. Consequently, a post-ozonation filtration step must follow the application of ozone to remove these insoluble materials formed during ozone oxidation step.

Some surface waters contain high algae levels during seasonal time periods. These should be removed from the water prior to application of ozone for disinfection. In many instances a preozonation step is used followed by coagulation/settling, screen filtration or simple gravel/sand roughing filters to remove the algae, followed by ozonation for disinfection and oxidation of organics, followed by filtration.

Once these aspects of ozone processing and the ozonation system are understood by State and local regulators, then the proper testing and approval of complete water systems which include ozonation can proceed in the regions overseen by the now ozone-educated regulators.

One of authors of this paper (K.O.L.) runs a water treatment business in the State of Washington (West Coast of the USA). When he first added ozonation systems to his product line, he ran into the problem of his State's regulators not having clear guidelines for establishing standards for new technologies as well as not understanding what ozone is all about. As a consequence, the installation of Washington State's first small ozonation system (1992) for iron and manganese removal required about a year just to obtain approval.

To overcome this situation, our co-author (K.O.L.) set about, in tandem with a local engineer, Mr. George Bratton, and working with the Washington State Department of Health, to develop a set of interim guidelines to be used by State and local regulators in reviewing and approving applications involving ozone for small community and non-community, non-transient water treatment systems. Among the primary concerns for this checklist were (1) setting standards which could demonstrate a reasonable chance for successful treatment, (2) establishing some equipment quality standards such as electrical code compliance and ozone compatibility to screen out unreliable ozone generators, and (3) assurances of safety for personnel involved in the operation of ozonation systems.

To meet the first requirement (reasonable likelihood for successful treatment), pilot plant studies are required to establish relevant factors such as ozone dosage required to attain specified treatment objectives and filtration loading rates. These studies can be small-scale pilots or a testing study run on the fully-installed system at the time of startup, which puts the burden on the vendor to make certain the system has been properly sized and designed. Water analyses from a State-certified laboratory are required to be submitted to the Department of Health with the checklist as proof of compliance with treatment requirements for each system. State approval of the system is dependent upon compliance with the checklist and testing standards.

On the issue of safety, three factors were covered: (1) operator exposure to ozone gas in the treatment room, (2) electrical safety standards for ozone production equipment (Underwriters Laboratories, Edison Testing Laboratories and Canadian Standards Association labels), and (3) issues of water quality including procedures for monitoring systems.

One of the major goals of establishing a checklist with the Washington State Department of Health was to eliminate equipment from consideration which posed either safety issues, such as electrical certification problems, or which are of such inferior sub-standard quality as to have an anticipated short operating life. Having been tested and used for several years in Washington, this checklist approach could be adopted by other states to streamline the approval process. In some States, which may be reluctant to approve ozone, vendors could submit this checklist to provide the regulator a means of issuing an approval with the knowledge that the checklist is based on some substantive standards or guidelines.

Another instance of regulatory resistance to ozone (or to any new technology) for small water systems lies in the speed at which federal drinking water regulations are moving through the U.S. EPA. The result is that many States, and particularly their small communities are not up to date in understanding what the treatment implications of new national drinking water standards might be. Until 1998, most small systems had not yet been required to meet the TTHM regulation with which the larger water systems have had to comply since 1982. In December 1998, EPA lowered that standard, added total haloacetic acids, bromate ion, etc., and now apply them and microorganism cysts and viruses to the lists of substances to be regulated (U.S. EPA, 1998a). It is small wonder that local regulators of small water systems may not be up to speed with new technologies to solve their problems.

As a general recommendation, regulators should not over-regulate or micro-manage to the point of stifling innovation or limiting competition among reputable, successful vendors. Regulators should also avoid the tendency to over-zealously require components or procedures, which can unnecessarily raise the price of a system to a small community. On the other hand, the regulators should adopt uniform rules for approving any ozone system for a small community and work closely with the industry and engineers to assure that only safe, quality equipment and installations are carried forward. In adopting these uniform rules, regulators must not place any higher burdens or more stringent requirements on ozone systems than they do on other technologies. By developing fair, accurate and uniformly applied regulations, regulators will be protecting the public while allowing further development of the ozone technology.

Perhaps the EPA/NSF Environmental Technology Verification program for packaged systems can incorporate what has been learned and proven to date and be embraced by State and local regulators.

Case Examples – Small U.S. Drinking Water Systems

In this section, several case examples of the incorporation of ozone into various sizes of small water systems will be presented. Included will be, to the extent available, costs and performance data.

MOUNT DESERT, MAINE

Two potable water plants incorporating ozone were installed originally in the Mt. Desert villages of Seal Harbor and Northeast Harbor in 1994 for what were then two separate, private water companies. In April 1997 the two water companies were bought out and merged to form the Mount Desert Water District, a quasi-public entity. Each of these small plants is at the upper end of EPA’s small water systems scale.

System flow is set to 700 gpm during the summer, and 350 gpm during the rest of the year. Typical summer demand varies between 0.5 and 1-mgd, highly variable since the water is not metered at the customers' taps. There are very large summer estates with extensive ground-watering activities. Flow rates are highly variable depending upon weather conditions. Seal Harbor source water is Jordan Pond; Northeast Harbor's source is Lower Hadlock Pond.

The water quality at both facilities is excellent; however, it is better in Seal Harbor. Although the same size ozone generators [two (2) 7 lb/d air-fed] were installed at each facility, those for Northeast Harbor apparently were undersized. The original plan was to have two redundant, parallel process ozonation trains for disinfection using sidestream injection contacting and pipeline detention for C·T credit. Although this approach worked for Seal Harbor, it was found that both trains had to be operated in Northeast Harbor during the summer, high flow months. This was unacceptable in terms of providing backup equipment capabilities to satisfy the regulatory agency.

Both systems are entirely gravity fed from two separate surface water supplies. The system flow rate is variable based on demand -- there is no storage in either system. Both systems operate under avoidance from filtration waivers; e.g., the water is not filtered following ozonation. Ozone is applied for disinfection purposes to meet the requirements of the Surface Water Treatment Rule. The "C·T" value for ozone at 1°C and pH 6.6 (raw water pH) to assure 3-logs inactivation of *Giardia lamblia* and > 5-logs inactivation of enteric viruses is 2.9 (mg-min)/L. This C·T requirement coupled with the experimentally determined half-life of ozone in these waters (17-20 minutes) resulted in the decision to develop a residual ozone concentration of 0.5 mg/L in order to guarantee a C·T value of 2.9 (mg-min)/L at all times (Jackson and Overbeck, 1997).

Both facilities have had numerous problems since start-up. The originally designed layout allowed the ozone generators to flood if a sidestream pump shut down or cavitated and vacuum was lost at the gas eductor. The original design made no provisions for a dedicated contact chamber (contact time was assumed to occur in the transmission line, prior to the first customer, a significant distance away), and no provision for measuring or computing C·T values to ensure compliance with disinfection requirements.

The original plants were poorly instrumented, with no measurement of make-up air dew point or concentration or output (lbs/days at wt-%) of ozone generated. The original ozone generator control system worked very poorly. It was originally designed to pace to a flow meter reading and trim to an applied residual probe. The response time of the probe was insufficient and the two control functions were separated by the field technician at start-up. The system primarily was operated based on the flow meter pacing, with the applied dosage (C_0) reading manually observed.

It has turned out that the original ozone generation systems likely never provided their rated ozone output due to poor air drying equipment. In 1997 a newly-hired consulting engineering firm began looking at the problems in order to recommend equipment and design modifications. When this firm began to instrument the facilities, it was found that dew points of +10 to -10ºF were being achieved in the air feed gas (much higher dew points than recommended by any responsible ozone systems supplier). The units would foul in approximately 1-2 months of operation and were regularly requiring maintenance and cleaning.

Both facilities underwent the following upgrades in response to a Consent Agreement:

1. Both systems have converted to liquid oxygen (LOX) feed gas for ozone generators.
2. Original generators have been replaced with new generators (from another supplier), 2 x 9 lb/d in Seal Harbor, 2 x 17 lb/d in Northeast Harbor.
3. Storage (500,000 gal) has been constructed in each village.
4. Plants have been converted to on/off constant flow (operator set on a seasonal basis). Seal Harbor will continue to be a gravity system. Northeast Harbor will have a pump station added.
5. Contactor basins have been added to each facility. Ozone will continue to be added, using sidestream injection/degassing, at the head end of the contactor to ensure plug-flow conditions. A single downstream probe will determine residual and a special control system will report C·T values. A number of probe sites are installed so that the probe may be located optimally on a seasonal basis. The control system may be operated on the basis of a flow-forward, a constant applied ozone dosage, a constant ozone residual, or a constant C·T value.

Raw water flows past the ozone injection point under gravity; the sidestream motive water pumps draw off approximately 15% of the forward flow; ozone is added to the motive water, contacted in a small vessel (approx. 15 sec), excess stripped in a GDT™ degas separator, then injected into the main line; a modulating valve holds flow through the plant to a seasonally adjusted rate; treated water enters a plug flow contactor; a single ozone residual analyzer, which may be located at one of several positions along the contactor depending on season, measures residual; chemical additions including fluoride, caustic soda, and hypochlorite (ammonia in the future) then are made at the end of the contactor; and the water sent to storage. Ozone residual is measured just below the point of contact (C_0) as well as at the end of the contactor. The C·T probe is submerged within the contactor.

Mt. Desert currently is treating surface water only for *Giardia* cysts and viruses, although the community is considering what the regulatory future may hold. The THM formation potentials of the raw water supplies are over 80 µg/L, and both systems have relatively short transmission mains. The nearby community of Bar Harbor has a similar water supply, also operating under a filtration waiver, and using chlorine gas. Although this is a very simple, cheap system, the chlorine dose is quite high and contains a very long transmission line. The Mt. Desert consultants looked at going back to chlorination, rather than working with the existing ozone facilities. However, due to aesthetics, THMs, THAAs and eventual more stringent drinking water regulations, this approach did not seem appropriate.

Between the two installations, approximately $150,000 has been spent on upgrading the ozone generators to new, oxygen based units producing ozone at 10% by weight. This includes the bulk LOX storage facilities. LOX consumption is anticipated at about $10,000/yr in Northeast Harbor and $5,600/yr in Seal Harbor. This is based on bulk deliveries in Northeast Harbor and cylinder deliveries in Seal. Present power costs for both facilities will be reduced from

$40,000/yr using the existing 2% in air ozone units to $20,000/yr for the new oxygen-fed units. The existing equipment has operated poorly due to insufficiently dry feed air. This has resulted in significantly less than rated output, requiring both generators to be on-line constantly in order to meet residual ozone requirements and by elimination of the air compressors, which have run continuously.

Approximately $2 million in other work is being done to both systems as well. The bulk of this work would have to be done regardless of the disinfection system used. For one thing, neither distribution system presently has any system storage. In the past it has simply flowed through the plants at whatever the system demand was. This has ranged from 150 gpm to 1,500 gpm. It makes it hard to dose, and particularly hard to perform maintenance on the equipment.

The original systems sold to the town were poorly thought out, poorly engineered, and the air preparation system was woefully inadequate. Once the upgrades have been completed, the communities are expected to be happy with the results. The trustees have said that they do not want water like Bar Harbor's.

Mt. Desert Consultant's Recommendations to Small Communities Evaluating Ozone

1) Do not scrimp on instrumentation. The original Mt. Desert plants were so poorly instrumented that it took literally years just to figure out what the problems were.

1) A major mistake with the first installation is that apparently the equipment suppliers were treated simply as vendors and were not involved in the design or even larger discussions of how the plants would operate. This resulted in a lack of buy-in by the equipment suppliers on the facilities. When it came time to figure out what was going wrong, it was very easy to say "Don't ask us, we just supplied what was asked for." This time, the new Mt. Desert consultants are involving the suppliers in their design vision and demanding that they provide an operable package and control system.

A second type of problem that these facilities suffered from was a continuously changing regulatory climate. For several years there was a steady turnover in regulatory personnel inspecting the facilities and reviewing monthly reporting. At certain times the feedback was that "everything is looking great." This was a real disservice which to some extent got the Mt. Desert systems into the present problems. This has definitely changed.

For now, the new Mt. Desert consultants remain quite positive on ozone treatment for small facilities. Their biggest current concern is how to monitor and report C·T values. This clearly was never thought out by the first designers. To be fair, it does not appear that much regulatory input was provided at that time.

THE VILLAGE OF SUBLETTE, ILLINOIS

Information regarding this installation was developed during and subsequent to a site visitation in December 1993 by the senior author (R.G.R.).

The Village of Sublette, IL has a normal population of about 400 persons. However, a large campground on the outskirts of town sometimes swells the weekend population to as high as 35,000 people, which exerts a significant increase in water demand. Raw groundwater supplies contain high levels of ferrous iron (1.6-1.8 mg/L), total iron (1.8 to 2.4 mg/L), manganese (above 0.30 mg/L), ammonia (0.98 mg/L), and iron bacteria (from 75 to 30,000 colonies per mL). Prior to process revision and installation of ozonation, the finished water (treated by conventional chlorination) was not a threat to health and was not consistently offensive, but occasional incidents of rusty water, mossy growth in toilet tanks and changing tastes left much to be desired, particularly from the point of view of the permanent residents.

The former water treatment process involved chlorination (13 mg/L applied so as to meet a 1 mg/L residual requirement), fluoridation and no filtration. Flushing of village mains was required monthly due to buildup of precipitate, which required 50,000 to 75,000 gallons of product water.

In April of 1990, an engineering firm was hired to study and compare alternative treatment methods. The preliminary cost estimate for construction of a state-of-the-art chlorination, aeration/detention system was $279,000 + $7,800 in consulting fees. However, this did not include the purchase of 3-3.5 acres of additional land space required for the system's retention and backwash detention tanks, nor for extensive piping between the proposed treatment facility and the storage tank. Just before a contract was to be signed for this system, ozone was brought to the attention of the village president by his brother, who had recently installed a residential ozone system for his farm that was producing crystal clear water from the iron-, manganese- and bacteria-laden raw water that came from the farm's well, of a similar quality as that of the village.

A pilot plant evaluation was conducted for Sublette by a local ozone equipment supplier in a mobile trailer over a period of several months. Volumes of water treated during the pilot plant testing program were sufficient to supply half the village requirements with fresh, potable water. That allowed for easy and reliable scale-up, especially with respect to filter performance. The fully automated ozonation system is of German manufacture (Hydrozon), available at the time through Carus Chemical Company, Peru, IL.

The Ozonation Solution – Two Stages of Ozonation + Dual Media Filtration

The treatment process selected for the village of Sublette consists of preozonation (to oxidize iron and manganese, to destroy odor-causing iron bacteria, and to saturate the water with dissolved oxygen), filtration through a two-stage granular activated carbon + sand/anthracite filter, a second ozonation step to assure bacterial disinfection, followed by low level chlorination (1 mg/L) for residual maintenance in the distribution system, followed by fluoridation.

A total of 4 lbs/day of ozone can be generated (from desiccant-dried air) at Sublette from a 3 kW power supply to treat a water flow of 127,000 gal/day. Ozone demand of the raw water was determined to be 6 mg/L during pilot plant testing.

Pilot System Test Results

Among the benefits achieved during pilot testing were the following:

1. Iron levels were reduced to less than 0.01 mg/L.

2. Manganese levels were reduced to 0.008 mg/L in the treated water.

3. Chlorination was decreased from 13 mg/L to 1 mg/L. This low amount of chlorine forms monochloramine with ammonia naturally contained in the raw water (0.98 mg/L) for protection of the distribution system.

4. Filter backwashing is necessary once every 18 hours of production, and uses approximately 1,500 gallons of water per backwash, or about 6,000 gal/week. This amount of finished water used for backwashing is far less than that used for flushing the lines during the old process (e.g., over 2 weeks: 12,000 gal today vs 20,000 gal minimum to flush hydrants in the distribution system, plus several hours of operator time).

5. The filter bed design and backwash parameters result in efficient removal of contaminants, even immediately after backwashing.

6. The treated water from the system is of high quality -- low turbidity and very clear with no discernible color, taste or odor.

7. The system is easy to operate and maintain. Due to its sophisticated program, process functions can be controlled in either automatic or manual mode. Alarms and shutdowns with first-out indications are provided for all major process functions.

The Sublette plant with its newly installed Hydrozon water treatment system started up on November 1, 1991. The Hydrozon treatment plant is compact and is installed in a small garage that is a part of the municipal building. The treated water is pumped to the existing storage tank. The water treatment plant operates only an average of nine hours/day to satisfy the normal water demand of the village.

A Two-Year Reflection and Performance Review

Treated water quality today at Sublette is much higher than when it was being treated by the older process. Sheets, pillow cases, and white shirts now come out of Sublette's launderings as white as snow, we are advised. However, one process modification has had to be made:

The Sublette plant is not operated constantly; actually it produces water only an average of nine hours/day. During down times, iron bacteria make their way from the raw water through the equipment to the filter, where they congregate, reproduce, and produce foul odors. To prevent this occurrence, the city has implemented a program of chlorinating prior to filtration. This increases the total chlorine dosage from the design dosage of 1 mg/L to 3.5-4 mg/L.

This technique prevents the proliferation of iron bacteria on the filter media, but does not increase the organic chlorine byproducts (e.g., trihalomethanes, haloacetic acids, etc.), because the dissolved organic carbon level of Sublette's raw water is quite low (< 1 mg/L; chemical oxygen demand ca 8 mg/L).

Costs for the Sublette Ozonation System

Capital Costs: The total cost of the new system was $208,000 ($71,000 less than the chlorination/aeration/detention system would have cost). The retention tank that would have been required by the aeration/detention system is not necessary. The backwash water detention tank/sand filter for an ozone system is smaller and is installed in the front lawn of the municipal building that contains the well, thus the village did not have to purchase three acres of additional property or install extensive piping.

Operating Costs: Power bills at the Sublette water treatment plant average $16/day for the total water treatment process. The cost for ozonation (including air drying) is $1.50/day, with the balance of the power costs going to pumping and heating of the building. Chlorine costs have dropped to $1.80/day (1 gal/day of sodium hypochlorite solution). In addition, the ozone system supplier recommends that the village rebuild the ozone-generating head every two years, at a cost of $2,000 ($2.74/day). Monthly data from the village for the period Dec. 1992 through Nov. 1993 show the operating cost of water produced (total treated water less the backwash water) to range from $0.06 to $0.09 per 1,000 gallons.

SOME SMALL WATER TREATMENT PLANTS IN THE STATE OF WASHINGTON

Over 48 small communities in the State of Washington have installed ozonation and filtration systems since 1990. The sizes of the treatment plants range from about 17 gpm to over 1100-gpm. Below is presented pertinent available information, including costs, for a few of these community system treatment plants.

Immediately following are brief descriptions of two small community ozone plants in Washington State installed for surface water treatment. Although both are designed to meet the requirements of the SWTR, the reasons for selecting ozone and the goals of each project are different, demonstrating the flexibility of ozone to meet a variety of small community treatment needs.

Boistfort Valley Water Company, Adna Plant, Chahalis, WA

In the past, the 200-gpm Adna Water Treatment Plant had operated for years using a package filter plant. Water from the Chahalis River was either pumped directly into the plant or through infusion galleries, then treated with a variety of chemicals for coagulation and flocculation. Prechlorination also was used to aid in disinfection. Following a clarifier and gravity filter, the water again was chlorinated in a clearwell (4 mg/L applied NaOCl) before being pumped to distribution. This process was expensive and required a great deal of operator time. More importantly, customer complaints about taste, odors and chlorine spikes were common.

A decision was made, following research by the company's water system manager, to investigate ozone for pretreatment. The goals for any retrofit modifications to the treatment process were (1) reduce operating costs, (2) improve customer satisfaction by reducing taste and odor problems, (3) reduce chemical usage and (4) meet water quality standards, including the D/DBP Rule. A brief, small-scale pilot study was conducted by the equipment vendor to determine the ozone dosage and contact time required to achieve necessary C·T values required for primary disinfection and to demonstrate the use of ozone to meet the company's goals.

During the pilot study, odor and taste were easily removed by a small dosage of ozone. Determination of C·T values was more difficult because of various factors related to the relationship between ozone dosage rates and contact time. A decision was made by the vendor and the plant manager (partly due to space limitations) to establish a contact time value (T) of five minutes (approved by the State) in the two 500-gallon ozone contact vessels (arranged in series), then adjust the ozone dosage based on calculated ozone demand determined by the pilot study to meet the required total C·T value. The dosage rate was established by measuring ozone residuals every thirty seconds for a period of five minutes until the resultant figure met the requisite value. The "C" value for residual ozone is an average of three sampling points (a) just after ozone injection, (b) as the water enters the first 500-gal contact vessel and (c) as the water enters the second 500-gal contact vessel.

Water temperature in the river varies widely during the year, from a low of 15ºC in the winter to a high of 26ºC in late summer. Turbidity also varies greatly depending on the river's flow conditions.

Following the pilot study, the water company purchased a 4.2 lb/day air-cooled corona discharge ozone generator utilizing oxygen concentrators for feed gas preparation. The project also included two 500-gallon stainless steel tanks built locally for contact vessels. These baffled tanks and the complete ozone production system were installed in a space made available by the elimination of chemical storage requirements. In other words, the floor space left when bulk chemicals were removed was sufficient for the entire ozonation pretreatment system, including the two ozone contact vessels.

The ozonation system retrofit cost the company approximately $50,000, which will be paid for ultimately in chemical savings alone in approximately two years. Specific costs of producing water are not available, but company management advised that the ozone system retrofit increased water costs to consumers by only about ten percent.

The resultant plant treatment process is the following:

Transfer pumps at the river
Booster pump to assure proper pressure and flow through venturi injectors for ozone mass transfer
Two 500-gallon contact vessels operated in series for 5 minutes detention time
Gravity filters, which includes a sedimentation chamber on the intake end, then tube settlers, followed by mixed-media and anthracite filter media
Chlorination in clearwell (maximum dosage = 0.6 mg/L NaOCl (compare 4.0 by old process)
Pumped into distribution

After operation for two years, when asked if the ozone showed the benefits expected, the company management responded: “Better results than expected”, then further described the benefits of the ozone treatment as resulting in better taste, no odor, lower chlorine levels, less coagulants, longer filter runs and less operator time. During the first summer of operation, the plant did not receive one water quality complaint from Adna Treatment Plant customers -- a new record for the company.

Testing for TTHM was conducted by sampling chlorinated water from the distribution system. Concern for disinfection byproducts and Stage 2 (D/DBP Rule) trihalomethane levels has been satisfied with TTHM results reaching a maximum of only 29.9 µg/L. Further testing will be conducted on THAAs and TOC during the summer of 1999.

LAKE MARGARET, DUVALL, WA

Lake Margaret is a beautiful 49-acre lake on the west slope of the Cascade Mountains. The community around the lake which had used ground water began running short as the community grew beyond the capacity of the well to meet demand. The community has water rights to the lake, so they began investigating surface water treatment.

Unlike the retrofit at Boistfort Valley described above, the Lake Margaret plant was to be an entirely new system. Not only were decisions required on such issues as necessary flow rates, but also the most appropriate technology had to be determined. In 1994, a volunteer in the community, Mr. Dexter Burlingame, a retired engineer, began a pilot study which was supervised by an engineering firm and monitored by the State Department of Health. The initial plan was to test filtration and chlorination.

From October 1994 until the end of January 1995, pilot system testing showed little reduction in TOC levels, although turbidity levels and coliform destruction were good. A problem was found during laboratory testing, however that caused the community to change its direction.

Trihalomethane levels were far beyond that considered feasible in meeting current, much less future, disinfection byproduct rule requirements.

To overcome this chlorination byproduct problem, ozone was added to the pilot system in February 1995. TOC, turbidity and UV absorption levels immediately dropped without making any other changes in the pilot operation. Laboratory testing for disinfection byproducts confirmed that the plant should meet D/DBP Rule requirements, including Stage 2 levels, by using ozone followed by chlorination.

The plant operator stated that the purposes of using ozonation, in addition to meeting the requirements of the D/DBP Rule, were to meet SWTR CT requirements for primary disinfection, improve taste and odor of the lake water, remove color and reduce soluble iron and manganese levels which exceed state MCLs in the raw water supply.

The full plant went on line in August 1997. The final design and installation incorporates the following treatment scheme into two independent treatment trains with a total treatment flow rate variable from 15 gpm to 80 gpm (average daily use is 18,000 gal):

> Water pumped from the lake to a pumping vault
> Gravel roughing filter, then pumps
> Ozone injection using side-stream venturi injectors and boost pumps to ensure proper, constant flow and pressure through injectors
> 3-pass, stainless steel contact vessels providing 3.6 minutes at peak flow and 9.0 minutes at minimum flow rate (C·T values average annually 3.2 mg-min/L)
> Residual ozone leaving the contactor is destroyed by UV units
> Off-gas ozone is vented from the contact vessels to an activated carbon ozone destruct unit
> Slow sand filtration
> Finished water pumping vault
> Chlorination pump for sodium hypochlorite
> 69,000 gallon reservoir and pressure pump station, then into distribution

Turbidity of raw water varies from 1.0 to 3.0 NTU. The turbidity MCL of <1 NTU (current Washington State regulation) is met consistently after the roughing filter and ozonation alone. After the slow sand filter, turbidity is reduced further. Water temperature ranges from a summer high of 23ºC to a winter low of 3.5ºC. Algae blooms can occur during the late summer, but are handled well by the roughing filter and ozonation without any change in finished water quality.

The ozonation system, including the injectors, stainless steel boost pumps, oxygen generators, ozone generators, stainless steel contact vessels, UV ozone destruct, automatic air release valves and off-gas ozone destruct units, ambient ozone room safety monitor and alarm system, cost the community approximately $53,000. Installation of this equipment was about $7,000.00. Operating costs for the plant are lower than expected, with an estimated cost of $0.15 per 1,000 gallons of treated water. TTHM laboratory results show no problem meeting the D/DBP Rule, including Stage 2 levels. TTHM quarterly results were 15, 20, 20 and 23 µg/L. THAA and bromate ion testing remains to be conducted. Raw water TOC levels of 2.6 mg/L are reduced substantially in the ozone treatment process. Iron and manganese removals were quite effective with ozone oxidation to 0.1 and 0.008 mg/L, respectively. Color is reduced from 30 CU to < 10 CU.

When asked whether the ozonation system has shown the benefits expected, the plant operator responded: “Totally!” Then, he added, “And, I only average about one and a half hours a day for all of the plant monitoring and operation.” With a smile, he concluded, “That includes mowing the grass.”

Below are case histories of several groundwater treatment plants in Washington that have installed ozone.

Mutiny View Manor, Whidbey Island, WA

Mutiny View Manor is a community of 71 homes and its water system is operated as a community association, with an elected board of directors. Management of the water system is primarily through volunteers in the community. This community has consistent record keeping and a continuity of management since before the ozone and filtration was put in (in early 1996).

Prior to installing the ozone system, the well water was untreated. Well water was pumped by submersible pumps into a concrete storage reservoir, then through pressure pumps into distribution. Customer complaints were numerous and manganese always exceeded the State Department of Health Maximum Contamination Limits for Secondary Contaminants [MCL]. Raw water manganese levels are at 0.5 mg/L [MCL in finished water is 0.05 mg/L] and iron is near the MCL at 0.3 mg/L. Tastes and odors also are present.

An EWS, Inc. ozone and filtration system was retrofitted into the existing system. The flow rate for the treatment system utilizes the full 60-gpm well production capacity. The following is a brief description of the process.

> Water from the well is pumped through a venturi injector [with bypass assembly].
> The venturi creates suction, which pulls air through an oxygen generator and a wall-mounted corona discharge ozone generator. The water exiting the injector is under pressure to provide motive flow to the remaining treatment processes.
> Mixing initially occurs at the injection point in the venturi, with further mixing and retention time (4 minutes) followed by use of a composite and fiberglass tank.
> From the contact tank, water splits into a manifold and passes through two filters, each equipped with automatic back washing controls. (Filter loading rate = 5 gpm/ft^2; Backwash rate = 12 gpm/ft^2)
> Filtered water moves directly into the concrete reservoir where level sensors in the reservoir control the “on” and “off” for the well pump, which turns the ozone production equipment on and off.
> Treated water from the reservoir is pressurized through the community’s existing distribution pump system, which is activated by pressure switches

Treated, filtered water from the reservoir is supplied to the filters for back washing, simply by teeing off the pressure line following the pressure pumps; thus eliminating the need for an additional back wash supply pump.

Since early 1996, the system operator has kept impeccable records and has completed a treated water analysis at least weekly. Manganese levels have averaged less than 0.015 mg/L throughout all of these tests. Iron and manganese have never exceeded their MCLs during that time.

Personnel time to operate the ozone and filtration system averages about ten hours per month, which includes taking extra time once per month to do a manual backwash to check filter operation and to complete the weekly field tests for manganese and iron. System management reports that customer satisfaction is quite high and that maintenance problems with the ozone and filtration system are virtually non-existent. Shortly after start up the retention tank leaked, which was replaced by the vendor under warranty. Some adjustment of the ozone dosage and filter backwash schedules also were required early on. For the past two years, however, the only service calls required were to complete the scheduled annual inspection and cleaning of the equipment by EWS technicians. There have been no expenses for the community during this time for repair or replacement of any components.

System operating costs are very low. Community records show that treating the water costs approximately $0.016 per 1000 gallons. The total operation cost for the community water system is $0.21 per 1000 gallons.

Capital cost for the ozone/filtration system was approximately $25,000, and a small building had to be constructed to house the ozone and filtration equipment. This cost was paid for through savings and assessment of home owners. The customers on this system pay a flat rate of $100 per year for water, plus any special assessments, which arise to cover system improvements and expansion.

Sky Meadows Community Water Association, Coupeville, WA

Sky Meadows is also located on Whidbey Island and is operated quite similarly to Mutiny View Manor as a homeowners' association. Water quality complaints were also similar and manganese levels exceeded the state MCL. Sulfide odors and taste complaints were common before the ozone system was installed.

Sky Meadows had operated two wells for 19 homes (34 lots) for several years with a Manganese Green Sand filtration system for iron and manganese removal. This system was often out of compliance and required a great deal of management and operator time. The expense of chemical purchases, storage and handling also influenced the association board to look at other alternatives.

Ozone and filtration were pilot tested for a week. Results were quite good and board members were impressed with the odor removal and the improved taste of ozone-treated water. The

Association purchased an ozone (1.5 lbs/day) and filtration system in 1996. The installed price for the system, which included removal and disposal of the previously existing green sand filters was approximately $37,000. The ozone and filtration system was retrofitted into the existing building, with only minor plumbing changes required. The system operates at 30 gpm treating water from two wells. Raw water manganese is high, at an average of 0.40 mg/L, and iron at 1.4 mg/L. Treated water meets all of the state requirements. Manganese levels range around 0.01 mg/L, with iron testing at non-detectable.

Customer satisfaction is high and operating costs are low, with an average production cost per 1,000 gallons of $0.046. Operating costs for other EWS small community systems in the Whidbey Island area have been ranging from $0.06 to $0.016 per 1,000 gallons.

<u>City of Ocean Shores, Ocean Shores, WA</u>

The City of Ocean Shores is a small beach town on the Pacific Ocean. In the winter, the town's population is about 3,300 persons, but in summer the population grows to 35,000. This ozone treatment system was designed to meet peak flows of about 1.44 mgd. The ground water supply comes from an aquifer with a number of water quality problems, including high color levels (one well has water at >250 CU), sulfur odors, elevated iron and manganese and resultant high turbidity levels. In 1996 and early 1997, the city and its engineering group conducted intense pilot testing of various technologies with a goal of being able to use the worst wells to meet peak season demand. The community's dependence on tourism and the extremely rapid growth of the community, especially the increase in summer visitors, made meeting peak demands even more critical.

The goal of the pilot testing, which included ozone and filtration, activated carbon, coagulation and flocculation, as well chlorine oxidation and filtration was to have all parameters meet State MCLs. Color, turbidity, iron, manganese and sulfide ion all had to be addressed.

Ozone and filtration was selected, having shown promise in meeting all of the contaminant parameters described above. The system was designed as two 500-gpm treatment trains, each of which could operate alone or the two could run together.   Each treatment train is composed of a water-cooled, corona discharge (16 lbs/day in each treatment train) ozone generator, fed by OGSI oxygen concentrators. Ozone is injected into the water stream by means of a 4-inch Mazzei venturi injector, followed by a stainless steel contact tank and two 8-foot diameter epoxy-coated, carbon steel pressure filters. Filtered water flows directly into the City's distribution system under pressure, which runs at about 70 psig. Average operating time for the system is 10 hours per day, with higher runs in the summer and less in the winter. The system management has the ability to change the water source among any of five wells and can blend the well water as desired prior to treatment.

An existing manganese green sand filtration system continues to be operated for treatment of the less seriously contaminated sources, which consumes considerably more operator time than the ozone and filtration system for the more problematic water quality wells.

Capital costs for this facility were $423,000 (ozone, filtration system, stainless steel reaction tanks, controls, and instrumentation). Costs for ozone generation: 1353 kW/day = ca $0.15/1,000 gal of water produced.

The system has operated consistently since July 1997 (after a period of adjustment and repair of a broken pipe), with a daily treatment capacity of 1.3 million gallons. After this period of operation, the plant management reported that the ozone and filtration plant has met their anticipated benefits and that process benefits include lower chemical costs, better taste, no odor and excellent color readings.

Sun Vista/Sunlight Beach Water Association, Clinton, WA

This water system on Whidbey Island, Washington is privately owned by a community home owners' association, which incorporates two communities into a single water system. Management is through an elected board of directors, which has contracted with a local firm to provide certified water management services. These services include all day-to-day operations of the entire water system, meter reading, maintenance and repair of all facilities. A portion of the manager's salary was split off arbitrarily for accounting reasons and listed on the books as Ozone Filter Plant Operator, the balance of his salary and other charges are kept under General Water System Operations for accounting purposes.

Problems with sulfur odors as well as high iron (1.4 mg/L) and manganese (0.92 mg/L) led the association to look into water treatment in 1994. Following pilot testing, the organization purchased an ozone and filtration system from EWS, Inc. This treatment plant went on line in February 1995; thus, four years of data are available for this plant. The community had an existing pump house through which the two wells were plumbed. So, the ozone and filtration system was designed to fit within this infrastructure and to tie into the existing piping system between the wells and the reservoir.

The capital cost for retrofitting the EWS ozone and filtration system was $52,380, installed. These funds were paid for by accumulated revenue from water hookup sales and quarterly fees.

Two wells serve the community and are fed into a single pump house. Total capacity is 110 gpm from the combined wells. The ozone plant was installed so that it could automatically accommodate either well running alone, or both together. A ClearWater Tech air-cooled, corona-discharge ozone generator produces about 1.5 ppd at a concentration of approximately 2.5 % by weight. Feed gas for this ozone generator installation is dried, oxygen-enriched air containing an oxygen purity of about 80 %. Ozone is fed into either or both of two Mazzei venturi-type injectors, using energy from the submersible well pumps to create the suction required. No additional pumps are needed.

Ozonated water moves into a 48 x 72-inch composite tank, which provides retention times that vary depending on which combination of wells is running at the time. Design minimum retention time is four minutes. The oxidation of metal cations, iron and manganese, takes place quite quickly at the injector, but retention time is needed to allow the oxidized contaminants to flocculate sufficiently for effective removal by filtration. A pilot plant study is recommended to determine optimum retention times for various contaminants in a typical community well water applications.

Water from the contact vessel flows through a manifold to three 36 x 72-inch media pressure filters at a maximum loading rate of 5 gpm/ft^2. Filtered water continues out of the plant to a reservoir uphill. Static pressure on the system created by the reservoir is about 42 psig. Backwash for the three filters is triggered by a backwash controller and solenoid valves, which allow treated water from the reservoir to back-flow into the bottom of the filters and out to waste. The filtrate flows into a concrete vault for settling before gravity flowing over a constructed gravel and rock run into a neighboring wetlands area.

Because the system injects no chemicals and utilizes no salt brine solutions, the State Department of Ecology allows filtrate discharge into the environment without special handling or permits. After four years of continuous duty, there is no build up of iron and manganese on the gravel and rock area and the concrete vault has never been cleaned.

The contract performance standards for these iron and manganese removal systems is to maintain treated water contaminants -- primarily iron and manganese -- below the State MCLs of 0.3 mg/L and 0.05 mg/L, respectively. EWS, Inc. strives to maintain no more than 50 percent of the MCL for iron and manganese. Raw water iron [1.4 mg/L] and manganese [0.92 mg/L] far exceed State MCLs. After treatment, iron tests at non-detectable and manganese ranges in the area of 0.015 to 0.03 mg/L, both being well below the State and EPA limits. Objectionable taste and odor problems have been solved, including high levels of hydrogen sulfide.

A question often raised is whether pH adjustment is necessary to achieve manganese oxidation with ozone. At Sun Vista/Sunlight Beach the raw water pH is 7.14. No adjustment is required, nor has any adjustment in pH levels been made to achieve the iron and manganese removal at any of the EWS, Inc. groundwater systems. Because this system is groundwater, the water temperature remains fairly constant throughout the year with measurements showing a three-degree change at the most, from 10ºC to 13ºC. This variation may be explained by the shallow depth of the wells. Testing to determine whether they are under the influence of surface water is on-going.

The ozone dosage rate is based on the contaminants to be oxidized in relation to the flow rates. There is a wide variation in water demand during the year for this community, but the ozone dosage rates remain the same during winter and summer and the adjustment is made in the pumping times, rather than the flow rate. Thus, at constant pumping flow, filter loading rate and ozone dosage is achieved with fully automatic operation throughout the year. Ozone dosage rates will vary tremendously depending on the contaminants and the organic loading of the water. Typical groundwater systems in this area range from an ozone dosage of 0.8 mg/l to over 3.2 mg/L. The dosage rate for this system was determined through on-site, small-scale pilot testing.

Filter backwash is controlled by the Filter Wizard © controller, manufactured by EWS, Inc. This device is a micro-processor-based controller which allows any of the filter system parameters to be adjusted on-site without a computer. Backwash events can be triggered by the operator selecting either time and day, input from a remote sensor [such as pressure differential], gallons treated or manually. The unit has a *Virtual Totalizer,* which allows the operator to select a flow rate and trigger a backwash based on the estimated number of gallons filtered since the last backwash. Report functions provide excellent trouble-shooting data and the simplicity of operation allows untrained, non-certified operators to operate the filtration system successfully. At Sun Vista/Sunlight Beach, filter backwash is triggered by time of day and day of the week, being adjusted between peak summer usage and low winter usage.

On two occasions, warranty work had to be conducted on the ozone generator and periodic injector cleaning is performed by the certified operator. Costs to the association for service calls and repairs for the ozone production equipment and the filtration components have totaled only $60 in the past four years.

Operating costs for the ozone and filtration plant are primarily for electrical power, which is quite low ($0.06/kWh). An estimated cost for this electrical power is based on a total electrical draw of 8 amps at 220 V-ac, and 16 amps at 120 V-ac. Pumping time ranges from a summer peak of around 200 hours per month to a winter low of 90 hours per month. An estimated average treatment per day is 36,000 gallons, which requires approximately 23.8 kilowatts of electricity for the ozone and filtration system. Submersible well pump costs are not included here because those costs do not relate to treatment since they are required even with no treatment plant at all. Resultant cost for operating the ozone and filtration treatment plant based on these averages is about $0.039 per 1,000 gallons.

Each of the 153 connections on the system pays a flat quarterly fee of $40.00 for the first 4,000 cubic feet of water, plus $2.00 for every additional 100 cubic feet. Customers, as in most associations, can be assessed fees to cover the cost of future improvement projects and expansions if the normal fees collected cannot meet those costs. Management of this system by the elected board, as well as the certified operator, is forward-looking and progressive and their customer satisfaction appears to be quite high.

Woodglen Properties, Oak Harbor, Washington – groundwater supply to six homes - on-line in 1997

Water Quality Problem: iron (4.2 mg/L) and manganese (0.34 mg/L) + taste and odor
Water Treatment Rate: (22 h/day) – 11,880 gal/day
Ozone Production Capacity: 14 g/h
Filtration: multi-media @ 5 gpm/ft^2
Capital Cost of Ozone + Filtration System: $14,000 ($2,333 per home)
System Operating Cost: 1.9 kW (ca $3.34/day/system = ca $0.56/day/home).

Lagoon Point Water District, Greenbank, WA – ozone treats one of several wells for 516 community lots - (332 currently connected and occupied) - on-line in 1992

Water Quality Problem: iron and manganese removal
Water Treatment Rate: 79,200 gal/day
Ozone Production Capacity: 14 g/h

Filtration: multi-media @ 5 gpm/ft^2
Capital Cost of Ozone + Filtration System: $46,000 ($89 per lot)
System Operating Cost: 4.8 kW (ca $8/day for the well).

State of Washington "Estimated Residential Unit"

Several dozen additional small ozone installations now are operating in the State of Washington, all serving small communities of a few thousand homes down to clusters of a few houses, and all encountering the same raw water qualities and ozone/filtration treatment costs. Some of these ozonation systems have been in operation for over seven years as of this writing.

The State of Washington's Dept. of Health has developed an Estimated Residential Unit approach to sizing water treatment systems for small communities, With this system, a community's size is limited by the water production from its wells or surface source. As a starting point, each residential hookup must be allotted 800 gpd. Credits are allowed for large storage capacity and for other factors, such as proven conservation. However, based on 800 gpd per connection, the following estimates can be made based on appropriate assumptions:

1. The number of connections allowed per gpm can be estimated.
2. An estimated cost for ozone and filtration for a given gpm range can be made.
3. A resulting cost per connection can be estimated

Ozone System Cost Summary in Washington State Small Water Plants

Based on the actual experiences for the plants described above in the state of Washington only, costs for ozonation systems are summarized in Table I. It is clear that the operating costs for small ozonation systems in these sizes range from $0.039 to $0.15 per 1000 gal of water produced.

Applying prices for retrofitting several small communities with ozone + filtration results in the following estimates of capital cost per home (retrofitted into existing pumping system):

1.	System for 6 to 12 homes (up to 9 gpm total)	$2,333 to 916 per home
2.	System for 15 to 50 homes (up to 50 gpm)	$741 to 580 per home
3.	System for 60 to 180 homes (up to 100 gpm)	$750 to $361 per home
4.	System for 200 to 500 homes (up to 200 gpm)	ca $285 per home

TABLE I. COSTS FOR OZONATION SYSTEMS IN WASHINGTON STATE PLANTS

Plant - yr ozone on-line	**Raw water type**	**Size - gpm**	**Persons served**	**Water quality problems**	**Costs**		
					Capital	**Operating**	**to users**
Chahalis 1997 - retrofit	Chahalis river	200 gpm	731 connect’ns	T&O, 1☜ disinfect’n, DBPs	$50,000	not available	n.a.; lower chem costs and operator time
Duvall 1997	Lake Margaret	15 - 80 gpm	177 lots; 150 homes currently	T&O, 1☜ disinfect’n, DBPs, Fe, Mn, color	$7000	$0.15 per 1000 gal	not available
Mutiny Manor View, 1996	wells	60 gpm	71 homes	Fe, Mn, T&O	$25,000	$0.016 per 1000 gal, O_3; $0.21 total system	$100/yr
Sky Meadows, 1996	wells	30 gpm	19 homes; 34 lots	T&O, Fe, Mn	$37,000*	$0.046 per 1000 gal	not available
Ocean Shores, 1997	aquifer	up to 1.44 mgd	3,300 - winter; 35,000 - summer	color, sulfide, Fe, Mn, TOC (16 mg/L)	$423,000	$0.05 per 1000 gal (ozone only)	not available
Sun Vista, 1995	wells	110 gpm	153 connect’ns	sulfide, Fe, Mn	$52,380	$0.039 per 1000 gal	$40/ 4,000 ft^3 + $2 for each addnl 100 ft^3
Oak Harbor 1997	wells	14 gal/hr	6 homes	Fe, Mn, T&O	$14,000 ($2,300 per home)	$3.34/day	$0.56/day/home
Greenbank 1992	wells	79,200 gal/day	516 lots (332 connected)	Fe, Mn	$46,000 ($89/lot)	$8/day per well	not available

* includes removal and disposal of green sand filters

SOME SMALL WATER TREATMENT PLANTS IN THE STATE OF CALIFORNIA

The Triple O Systems, Inc. Ozone Treatment System[1]

This unique water treatment system consists of an ozone generator, an injector gas/liquid mixer, and a cartridge filter module designed to treat water in a storage tank with continuous recycle. The system is unique in that whereas the generator and gas/liquid mixer are located outside of

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[1] Triple O Systems, Inc., 1610 Dell Ave., Unit N, Campbell, CA 95008; Tel: 408-378-3002; Fax: 408-378-7155

the storage tank, the cartridge filter is submerged and rests on or close to the bottom of the storage tank (see Figure 4). The system is designed specifically to oxidize iron and manganese and to continuously filter the insoluble materials our of the treated water. Periodically, the cartridge filter is removed from the tank, opened, the insoluble iron and manganese materials are removed by washing, the filter is re-closed and returned to its position at the bottom of the storage tank.

Also unique to this system is the fact that ozone is generated by ultraviolet radiation rather than by corona discharge. This avoids the necessity for air drying and lowers the capital cost. Were the approach to water treatment once-through, this manner of generating ozone would be insufficient to perform the oxidation and disinfection tasks. However, since the water is continuously recirculated through the ozonation system, the multiple exposure to low levels of ozone results in continued oxidation of iron and manganese as well as ultimately building up sufficient dissolved ozone to ensure that bacterial disinfection is attained.

Each Triple O Systems unit has a suggested retail price of $1,595 to an individual homeowner. To this should be added the cost for the storage tank, which varies from site to site. Operating cost is on the order of $3/month, which is for the amount of electricity required to produce ozone continuously. These are the ozone units are known to be installed in the 363 residences noted in Figures 2 and 3.

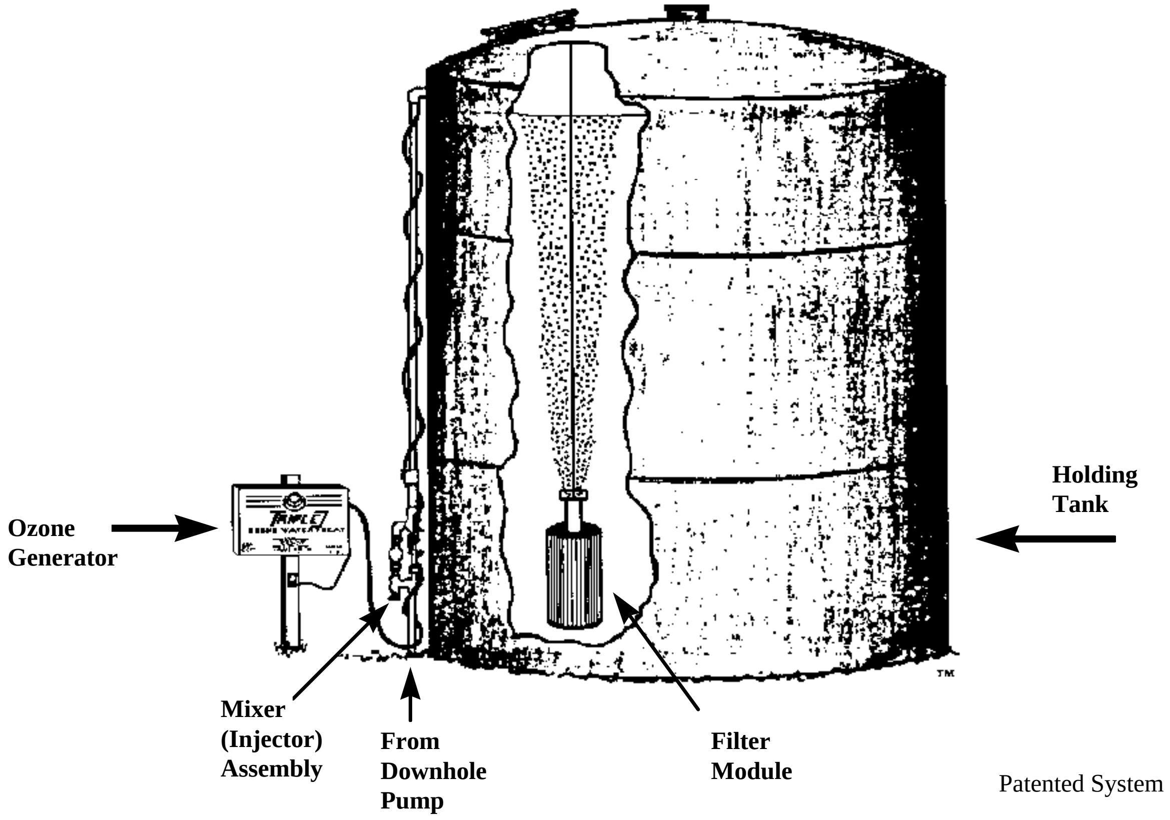
Mono Village Water District, Standard, CA

This system serves 350 homes and small businesses and has a peak daily water usage of 242,000 gal/day (peak monthly water usage in August = 7 million gallons). The Triple O Systems approach is used, which means that multiple units must be installed. The treatment system involves three storage tanks (tanks #1 and #2 hold 218,000 gal each and tank #3 holds 126,999 gal – total storage capacity is 562,000 gal). Well water feeds tank #1 and treated water from tank #1 feeds tank #2, where it is treated again, then feeds tank #3. Service water is drawn from tank #3. The three tanks use a total of 22 Triple O Systems units (8 each in tanks #1 and #2 plus 6 in tank #3). Units are placed in a circular pattern in each tank, approximately midway between the center and outside edge of the tanks.

Total cost for the 22 treatment units at Mono Village in 1992 was $24,000 and operating costs have averaged about $90/month (1210 watts electrical consumption ascribed to this treatment system). On the basis of the 350 homes and small businesses being served by the system, this equates to a capital cost of $68.57 per user and a monthly operating cost of $0.257 per user. Certified testing for coliform bacteria, *E. coli* bacteria, iron and manganese in water exiting tank #3 is performed monthly by an independent laboratory and reported to the State. Typical analyses are shown in Table II.

TABLE II. BEFORE AND AFTER WATER QUALITY AT MONO VILLAGE

Contaminant	Before Treatment	After Treatment
Iron	0.69 mg/L	0.02 mg/L
Manganese	0.26 mg/L	non-detectable
Turbidity	1.40 NTU	0.70 NTU
Coliform Bacteria	present	absent



Typical Above Ground Installation
Model TWTS-101

Figure 4. Schematic diagram of the Triple O Systems approach to water treatment in storage tanks.

Sources of Additional Information

The Water Quality Association (Lisle, IL) has an *Ozone Task Force,* comprised of manufacturers and suppliers of ozonation systems for small water/wastewater applications. This Ozone Task Force has developed several consensus documents in its brief lifetime. The first of these is a guidance document for determining the ozone output of generators on the market. Following this guidance procedure, a purchaser of ozone generating equipment will be able to (a) verify the production claims of the various equipment vendors, and (b) compare the ozone outputs of the various vendors.

A second document is the 1997 *Ozone -- A Reference Manual*, designed for point-of-use, point-of-entry and other small water treatment applications.

For a description of pilot study operations and a comparison of ozonation and chlorination for iron and manganese removal in small water systems, see Larson, 1996.

The International Ozone Association (Pan American Group located in Stamford, CT) collects and disseminates information on ozone for all applications. It publishes *Ozone: Science & Engineering*, the peer-reviewed technical journal of the IOA and *Ozone News*, a bimonthly news letter of the association. In addition, proceedings of most IOA meetings held since 1973 are available, along with several monographs on specific subjects (e.g., swimming pools, cooling waters) and recommended analytical test procedures.

Summary

Small systems can and do use ozone for many of the same purposes as do large systems if properly designed, installed and operated, and the equipment purchased meets quality standards or guidelines.
To utilize ozone advantageously on very small scale, appropriate engineering and design approaches need to be applied. For example, small amounts of air can be dried efficiently by desiccant dryers without the need for compressors and refrigerant dryers required for larger production units. In recent years, oxygen concentrators have begun to replace air drying equipment in small scale ozonation systems.

Since the great majority of small water systems use groundwater, most of the ozonation systems known to be in place treat groundwater, primarily for iron/manganese oxidation, sulfide destruction, color removal, and bacterial disinfection.

Of the 262 public water systems known to be using ozone in the United States, well over half produce less than 1 mgd of water.

An additional 363 single residential or small business ozone installations have been identified which use the novel approach of UV-generated ozone added to water contained in storage tanks on a continuous basis to oxidize and filter iron/manganese and to provide bacterial disinfection.

Since the acceptance of ozone in treating U.S. waters is only a recent phenomenon, not many State and local public health departments and their drinking water regulators are aware of systems available to apply ozone effectively, safely, and economically. Regional vendors of ozonation equipment are faced with educating these officials so as to gain more rapid approval of small ozone systems.

The use of ozone to treat water systems, large or small, has many advantages, foremost of which are (for small systems):

- Small size of equipment --easily retrofit into existing treatment plants or homes.
- Ozone can oxidize a wide variety of water contaminants and disinfect microorganisms at Lower dosages and reaction times than other water treatment chemicals.
- Absent bromide ion in the raw waters, ozone does not produce halogenated organic by-products, but can reduce concentrations of TTHMs and THAAs following chlorination.
- No chemicals need be purchased and stored when using ozone. This can mean lower operating costs, lower operator time required, particularly if the ozonation system is designed and installed with appropriate instrumentation and controls.
- A small community ozonation system is easy to monitor, operate and does not require a specially-trained operator.
- If properly installed and operated, an ozonation system is safe and cost-effective to operate.

Although applying ozone safely and cost-effectively for small systems requires care and use of quality components, engineering and installation do not pose any significant problems sizing and matching of all major components. However, is critical, e.g., the ozone generator, feed gas supply, gas-to-liquid transfer, contacting and ozone off-gas destruction.

Before attempting to apply ozone for treatment of any water, it is advisable to conduct sufficient pilot testing so that appropriate pre- and post-ozonation treatments can be designed into the overall water treatment system, if necessary. Only with very clean raw waters can ozone be used by itself in small water treatment systems.

Ozone was listed in August 1997 by the U.S. EPA as a “compliance technology” for meeting the requirements of the Surface Water Treatment Rule for all three sizes of small drinking water systems (U.S. EPA, 1997).

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