THE OZONE LAUNDRY HANDBOOK

A Comprehensive Guide for the Proper Application of Ozone in the Commercial Laundry Industry

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ABSTRACT

Applications of ozone in commercial laundry systems began in the late 1980s-early 1990s. Early installations showed promise for ozone to save considerable energy over conventional (thermal) systems. However, inconsistent performances of ozone equipment of that period coupled with a lack of in-depth understanding of how ozone was performing hindered commercial acceptance of ozone. With continued study and testing, these early misunderstandings about ozone have been overcome, and today many thousands of commercial laundry systems are using ozone successfully in many parts of the world. For example, more than 2,000 ozone laundry systems are operating in commercial laundry systems in the USA and another 2,000 commercial ozone laundry systems in the United Kingdom alone!

Based on proven performance data obtained from many of these successful applications of ozone in commercial laundry systems, the authors have developed an Ozone Laundry Handbook, intended to be a summation of current knowledge and a guide to the laundry owner/operator considering the use of ozone. The Handbook contains 10 chapters, including discussions of the economic, environmental and microbiological benefits of ozone in commercial laundries, a discussion of ozone technologies as they apply to laundry systems, a comparison of traditional vs ozone laundry formulations, methods of applying ozone for laundering, operator training and ozone safety, a discussion on facts and fallacies about ozone for laundering, and finally a chapter on the future of ozone for

laundering. The Handbook also contains a Glossary of Ozone Terms and an Index.

Key words: Ozone, Laundering, Ozone Laundering, Benefits of Ozone Laundering, Economic Benefits, Environmental Benefits, Microbiological Benefits of Ozone Laundering, Ozone Laundry Formulas, Ozone Laundry Methods, Operator Training, Ozone Safety, Facts and Fallacies in Ozone Laundering.

INTRODUCTION – Handbook Chapter 1

There are upwards of 200,000 commercial laundry facilities in the United States today. These can be free-standing laundry plants, located in hotels, hospitals, nursing homes, health clubs, resorts, as well as in penal institutions, athletic facilities, in coin-operated Laundromats, and in dry-cleaning establishments. These locations are using, *in toto*, tens of billions of gallons of water and massive amounts of energy each year.

In recent years ozone laundry technology has proven itself to be an effective tool in helping to reduce water usage and energy consumption while also reducing wash and dry times, ensuring the absence of microorganisms, and improving the quality and useful life of laundered products. There are economic advantages to an ozone system as well as microbiological and environmental benefits. Currently in the United States there are over 2,000 ozone laundry systems in place and as many as 3,000 more in the United Kingdom alone.

No organized, reliable reference material exists today that provides unbiased, scientific information for the prospective user of ozone laundry systems. The authors of this document have brought together leaders of the ozone and commercial laundering communities to describe not only the benefits and effectiveness of ozone technology as applied to commercial laundries, but also to provide a comprehensive guide for the application of ozone in the commercial laundry industry [1].

Early Evolution of Ozone Laundries

The concept of using ozone to assist commercial laundering was first introduced in the United States in the late 1970s-early 1980s, primarily in penal institutions. Many of those early ozone installations showed very poor performances. A second generation of ozone laundry facilities began to be installed in the 1990s that provided better performances. Early systems touted many of the same cost savings and energy efficiencies that are being promoted today. However, as is the case with many new technologies, not all aspects of ozone technology were understood or had been fully explored by the early vendors, and many promises that were made oftentimes were not fulfilled.

The primary shortcomings of early ozone laundry systems can be attributed to lack of ozone chemistry knowledge and poor business models (lack of adequate service and support) by the early ozone equipment vendors to this market. Ozone chemistries are different from those of traditional laundering, and must be taken into consideration in order to achieve all of ozone's benefits during laundering. The uniqueness of ozone as a wash additive had not yet been properly researched or developed so as to be able to deliver a high quality wash. Facilities were seeing savings from reducing water temperatures, but other results were poor, and end users had no resource to consult as an education aid. Nowadays however, many companies understand the most effective ways to maximize the potentials of ozone and today are able to deliver the cleaned, disinfected, bright and soft linens that ozone can provide, along with its many cost-savings, microbiological, and environmental benefits.

Some of today's modern ozone laundering systems offer controlled and even variable levels of ozone controlled at the generator level (normally a selector switch) instead of using a single applied ozone level for all washes. Also, a variety of systems include sensors to monitor and also, in some cases, to control ozone levels in the washers themselves. These newer systems are overcoming the blemishes with which some of the original systems marked the industry. Not only have ozone laundering systems and support been updated, but the marketplace also has evolved. The extensive demand for cost saving, disinfection, and "green" technologies has sent decision-makers in search of technologies such as ozone.

BENEFITS OF OZONE

There are three primary advantages to employing ozone in commercial laundries – economic, microbiological, and environmental. Each of these advantages is discussed in a separate chapter of the Ozone Laundry Handbook.

Economic Benefits of Ozone Laundry Systems – Handbook Chapter 2 [2]

A comparative evaluation of traditional vs ozone laundering was conducted at a California hotel having 104 rooms. The study was conducted over a consecutive 2-month period (one month traditional laundering and the second month ozone laundering. Many parameters were monitored so as to quantify the savings that can be attributed to the use of ozone laundering [3].

Figure 1 is a bar graph comparing the annual costs of the two laundering procedures, and Figure 2 is another bar chart showing the percent of annual savings found as a result of ozone laundering in the following categories: electrical energy, natural gas, water, chemicals, and labor.

These savings lead to returns-on-investment of 7.7 months, when labor savings are included.

In the United Kingdom, weekly savings in costs at three different establishments operating ozone laundering were quantified [2]. The establishments surveyed were a 50-bed care home (70% incontinence), a 90-bed care home (85% incontinence) and an 800-bed hotel (zero or little incontinence). Items quantified included electricity, gas, hot and total water, chemicals, linen and labor costs. Annual savings were found to be as follows:

50-bed care home (70% incontinence)	£ 11,311 annual savings
90-bed care home (85% incontinence)	£ 15,967 annual savings

800-bed hotel (no incontinence) £ 21,276 annual savings

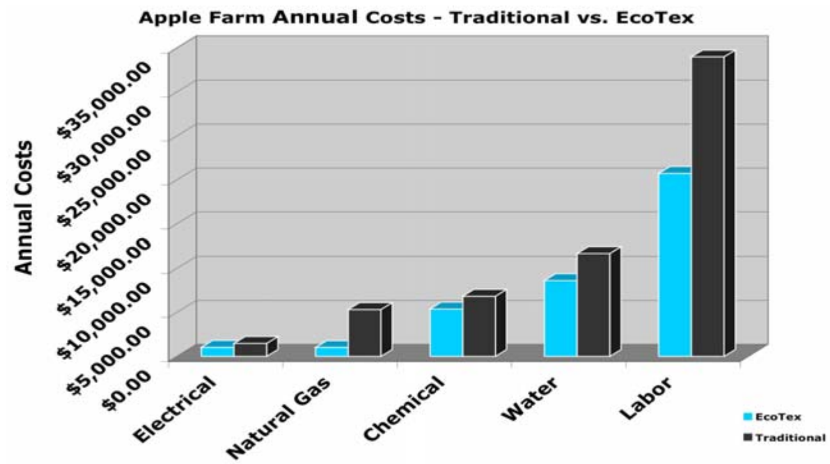

Figure 1. Annual costs of traditional vs ozone laundering at Apple Farm Inn, CA.

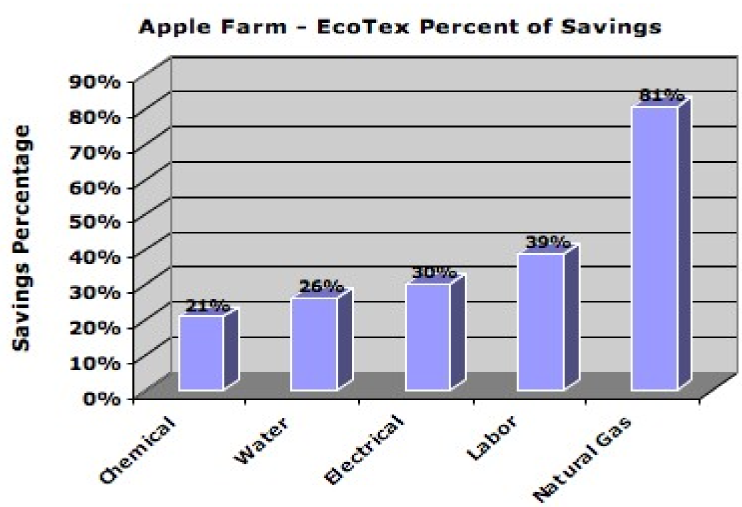

Figure 2. Percent of annual savings by ozone laundering at Apple Farm Inn, CA [1].

To summarize the economic benefits of ozone in laundering:

1. Ozone laundering brings reduced energy costs by using cold water (ambient temperature, from the municipal tap), which lowers the energy necessary to heat water. In the USA, these energy savings alone are in the range of 80-90%.
2. Ozone laundering eliminates the need for the amounts of many chemicals currently used in conventional laundering systems. These chemical savings amount to about 21%.
3. Because ozone laundering systems result in lower chemical usage, the number of rinses required is lowered, with resulting savings in water and labor. Labor savings alone amount to about 39%.

4. Fabric life is extended by ozone laundering, due to the lower temperatures required and lowered amounts of chemicals employed.
5. Confirmation of these cost savings in the UK shows total annual cost savings of ozone laundry systems ranging from £11,310 to £16,000 in two health care homes (with incontinent patients). In an 800-bed commercial hotel, these cost savings are as high as £21,275 per year.
6. Annual cost savings found for ozone laundering in the USA allow a return-on-investment between 7.7 and 17.4 months for ozone systems, depending on the size of equipment required and the work load – the amount of laundry that a facility must process.

Environmental Benefits of Ozone Laundering – Chapter 3 [4]

There are many environmental benefits of ozone laundering when compared to conventional laundering procedures. These include significantly decreased use of chemicals – which benefit the user of ozone laundering by lowering costs, but benefit the environment by decreasing discharges of chemicals in laundry wastewaters, and benefit the safety of the ozone laundry user by decreasing the storage requirements for laundering chemicals and the handling necessary.

When chemicals are discharged into the environment, they often can react with components of the receiving lakes, rivers and streams to produce byproducts which are not well degraded by natural microorganisms, and sometimes find their way into the food chain. On the other hand, when ozone does its work in a properly designed laundry system, its strongly oxidizing power actually initiates the oxidative conversion of most organic components of the soiling materials on the laundry to be cleaned into more readily biodegradable byproducts. This "preoxidation" of soiling components in an ozone laundry system then continues their biodegradation to harmless carbon dioxide and water as they continue to diffuse into the environment.

Additionally, when ozone is added to aqueous systems (in this case to laundry machines), the dissolved oxygen levels of the laundering waters rises. This is a significant advantage particularly when ozone is generated from oxygen-enriched air. The solubility of oxygen in water from a gas that contains mostly oxygen is several times higher than when that gas contains mostly nitrogen (as when air is used to feed the ozone generator). Higher levels of dissolved oxygen in laundry wastewater discharges benefit receiving streams, lakes, and rivers by providing oxygen for the natural microorganisms to do a better job of breaking down discharged pollutants into carbon dioxide and water.

Laundry wash effluent samples of a typical nursing home were analyzed for COD levels comparing the effects of conventional (thermal) laundering to ozone laundering on this parameter [5]. The results showed lower COD levels in the ozone wash and final rinse waters:

Thermal Cycle - Main wash	3890 COD mg/L
Thermal Cycle - Final Rinse	171 COD mg/L
OTEX Cycle - Main Wash	2000 COD mg/L

OTEX Final Rinse	145 COD mg/L

Ozone also is an effective deodorizer that works by breaking molecular bonds of many organic and inorganic compounds typically responsible for odors that are found in and on soiled laundry – particularly those received from hospitals and health care facilities which often house incontinent patients.

The UK's WRc-NSF Ltd. conducted an Independent Risk Assessment [6] of the impact of discharging spent laundry wash water that had been treated with ozone. It was concluded that wash water treated with ozone is safe to discharge to the sewer system; indeed any such aeration of sewage can be seen as beneficial since it encourages the breakdown of the organic matter and aids the sewage treatment process.

In late 1997, the Hong Kong Environmental Protection Department confirmed compliance of effluents of the laundry system at the Chi Lin Monastery (operating an ozone laundry system) with the required discharge limits for foul sewers under the (Hong Kong) Water Pollution Control Ordinance [7].

To summarize the environmental benefits of ozone laundering:

1. Reducing the amounts of chemicals and rinse water used in conventional laundering decreases the volume of wastewater discharged from the laundry as well as decreasing the amount of laundering chemicals discharged to the environment.
2. Ozone itself can be considered to be a "green" chemical, in that if any dissolved ozone remains in laundry discharge water, it will quickly convert to dissolved oxygen upon contact with dissolved organic materials present in surface waters. In turn, dissolved oxygen benefits microorganisms present in receiving natural waters or in sewage treatment plants.
3. As ozone oxidizes organic soils on laundry, the oxidized materials become more easily biodegradable by microorganisms in sewage treatment plants and/or receiving waters.
4. Lowering the amounts of laundering chemicals also increases the safety of laundry personnel, since smaller volumes of chemicals need to be stored and handled.

Microbiological Benefits of Ozone Laundering – Chapter 4 [8]

A major benefit of ozone in commercial laundry systems is the control, disinfection, and/or total eradication of microorganisms normally found in/on soiled laundry. In hospitals, health care, retirement facilities, as well as in locker rooms of academic and professional athletes, certain microorganism strains exist and proliferate that are particularly resistant to modern medications. Numerous infections from the two currently prevalent "superbugs" – Methicillin-Resistant *Staphylococcus aureus* (MRSA) and *Clostridium difficile* (*C. difficile*, or "C. diff") have created panics in recent years in various countries around the Earth.

Detailed studies conducted in the United Kingdom [2] on both the "routine" microorganisms found in hospital and health care facilities (*E. coli*, *Pseudomonas aeruginosa*, etc.) as well as many types of viruses, showed that these and the two superbugs (MRSA and *C. difficile*) are rapidly eradicated by ozone cold water laundering within 3-6 minutes. These studies also have shown that *C. difficile* spores are not consistently eliminated from microfiber mops and wiping cloths by conventional (thermal) laundering processes. This means that this superbug can be spread around the facility when reused after conventional laundering, thus increasing the potential for possible re-infection of patients, staff, and visitors.

Nurses' Uniforms Contaminated with MRSA [4]

Care labels of nurses' uniforms commonly carry the recommendation that they be laundered at 40ºC (104ºF). Therefore a comparison of thermal washing (40ºC) with ambient temperature ozone washing was conducted on soiled nurse uniforms into which were implanted membranes impregnated with MRSA. After 40ºC laundering, MRSA was clearly present on the membrane samples, but totally absent after ozone laundering. Data obtained indicated a > 8-log reduction (> 99.999999%) in MRSA on garments washed with ozone, but only a 3.3-log reduction (99.93%) after thermal washing at 40ºC (104ºF).

Six-Month Hospital Evaluation of Ozone Laundering

The Queen Elizabeth II Hospital (Welwyn Garden City, Herts., UK) first conducted testing of microfibre mops and wiping cloths contaminated with various microorganisms found in hospitals by conventional laundering (thermal disinfection at 71ºC = 160ºF over 60 minutes) and with detergent. Microbiological analyses showed the mops and cloths to be still contaminated. *C. difficile* counts were over 150,000 TVC (total viable counts). This means that even after the recommended thermal laundering, microfibre mops and wiping cloths were simply distributing *C. difficile* spores throughout the hospital.

An OTEX ozone laundering system that diffuses ozone directly into the sump of the washer through an Interfusor™ device was installed in the QE II Hospital and a 6-month trial of this system began on May 17, 2005. Microbiological analyses of microfibre mops and cloths sampled during April 2005 (before ozone laundering testing began) established a "control base line". Many problematic bacterial species were present, including MRSA and *C. difficile*.

Microfibre mops and wiping cloths taken randomly from the existing "live laundry" bins were processed every week of the 6-month trial period in the ozone-ambient temperature washing system. One sample of mop or cloth from a bag washed was analyzed before and after ozone laundering.

Throughout the 6-month ozone laundering trial, no residual target organisms, as set by the East and North Hertfordshire NHS Trust Infection Control, were detected, including MRSA and *Clostridium difficile,* after laundering with the ozone system. In addition the *ozone* system provided a simple laundering process with one cycle, which also can accommodate traditional cotton mops while using less detergent and being energy efficient.

Performance data comprised a total of 53 individual samples of microfibre mops and wiping cloths taken weekly from in-use laundry bins of the QE II Hospital. Most samples (but not all) were contaminated with MRSA, *C. difficile*, *A. niger*, yeasts and molds. After ozone laundering, every single one of these 53 samples showed zero cfu in each of the microorganism categories analyzed.

Based on this 6-month evaluation, the Queen Elizabeth II hospital adopted the ozone diffusion laundering system as their method of laundry decontamination in December, 2005.

Follow-Up Testing of Ozone-Laundered Microfibre Mops and Wiping Cloths

Another study was conducted at the QE-II Hospital to determine the effects of repeated ozone laundering on the physical properties of new and ozone-laundered microfibre mops and wiping cloths [9, 10]. Results obtained in this study indicated the following:

! Color loss is experienced irrespective of either washing under current HSG (Health Safety Guidelines) guidelines utilizing thermal disinfection or ozone disinfection wash cycles.

! No association between color loss and fibre damage resulting in a reduced performance was found. This finding is supported by information on color loss supplied by one of the microfibre manufacturers.

! No chemical damage/erosion was found in any of the samples evaluated.

! There is evidence that physical damage to the microfibres occurred during laundering. However, the data also shows that the cloths processed with ozone exhibited ***less*** damage than those processed by thermal laundering. The damage is localized on the tips of the fibers and is indicative of exposure to high temperatures during the drying process.

! The effect of physical damage was shown by the loss of the original surface area together with a corresponding reduction in the original absorbency. The physical damage is likely to be a result of drying at high temperatures for prolonged periods, since the cloths are polymers or "plastic" and are therefore susceptible to heat. Processing mops and cloths together also will have a detrimental effect on the cloths by increasing the physical action or abrasion of the materials.

The results obtained showed clearly that the use of ozone laundering does not result in any detrimental effect to the microfibre effectiveness or integrity and is a viable alternative to thermal disinfection. In contrast, there is evidence to show that the use of ozone maintains the microfibre integrity, with the added benefit of an improved disinfection process and additional utility savings.

Microfibre laundering via the ozone process subsequently has been carried out at several sites including nursing homes and hospitals with no adverse reports on their performance. One installation which currently has 12 ozone trial sites has been laundering microfibre items for over three years with ozone, with no apparent detrimental effects [10].

Comparative Testing of Ozone vs Standard Laundering [11]

Based on an August 2006 evaluation of an ozone laundering system, Reid *et al.,* 2007) [11] conducted a phase 1, single blind, randomized, controlled series group study of standard laundry disinfection techniques using the current standard VIKING machine versus a validated ozone laundering system (OTEX, from JLA Ltd.), set up at the laundry at Woodend Hospital, Aberdeen, Scotland.

The objectives of this study were to assess the safety, tolerability and efficacy of an ozone laundering system *versus* standard laundry cleaning procedures (VIKING machine). In addition, it was deemed important to assess the reproducibility of the OTEX ozone diffusion with Interfusor™ disinfection system on a standardized series of heavily fouled laundry loads contaminated with hospital-acquired bacteria, fungi and/or viruses in comparison to a matched series of heavily fouled laundry loads using the Standard VIKING laundry machine.

Forty (40) loads of very contaminated hospital laundry were processed comparatively as follows:

a. One washing cycle with conventional chemical products (detergent, alkalis and 150 ppm chlorine), humidification and pre-wash),

b. One washing cycle with ozone (up to 4 g per hour)

The mean reductions in log levels achieved post-wash by the two different methods were compared by t-tests, since the reductions were normally distributed. No statistically significant differences in reduction levels by ozone and conventional processes were evidenced in any of the five categories compared. Mean reductions fluctuated for the two methods over the five categories, but not in a significant manner.

Ozone laundering gave significantly lower mean levels for *C. difficile*, eliminating this microorganism completely. Additionally, ozone laundering provided a zero mean for *C. difficile* and much lower standard deviations than by the conventional laundering process. MRSA had a zero mean for both methods. The *C. difficile* difference and the differences in variations are visually clear in the box plot (Figure 3).

As a direct result of this comparative test conducted by Reid et al. [11], the United Kingdom's Health Protection Agency approved the OTEX ozone diffusion with Interfusor™ laundering system (JLA, Ltd.) in September 2009 with the following wording:
(http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1257260361418) :

September 09
JLA Ltd – OTEX Laundry System
Basic research and development, validation and recent in use evaluations have shown benefits that should be available to NHS bodies to include as appropriate in their cleaning, hygiene or infection control protocols. (recommendation 1)

This product is a commercial laundry system that uses ozone in all of the wash cycles

Evidence shows that it is more effective in decontamination than current laundry systems.

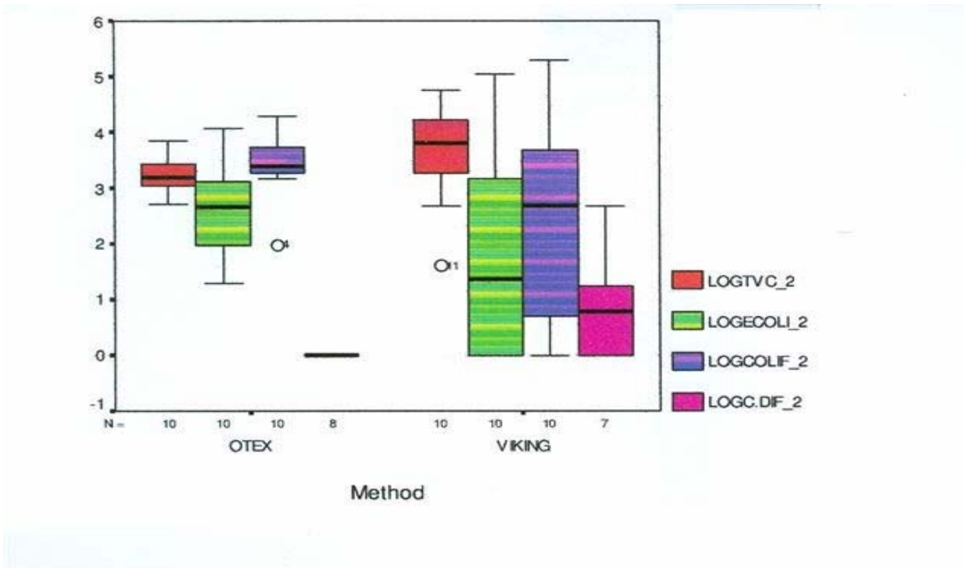

Figure 3. Box plot of post-wash *C. difficile* levels by method of wash (personal laundry) [9].

OZONE TECHNOLOGY – Chapter 5

The properties, chemistries of ozone in water and in air, methods of generating ozone (corona discharge and ultraviolet radiation), methods of contacting ozone with water, and methods of analyzing for ozone in water and air are discussed in this chapter as these topics relate to laundering with ozone.

TRADITIONAL VS OZONE LAUNDRY FORMULAS – Chapter 6

In this chapter the relationships between laundering formulations of traditional chemicals are compared to laundering formulations when employing ozone. The use of ozone sometimes has effects on the amounts of traditional chemicals and laundering formulations now required. Equally important are the effects of washer agitation, selection of water levels and durations of these steps.

The simultaneous use of ozone and high water temperatures for laundering is mutually exclusive. This is because temperature not only aids in the decomposition of ozone, but also aids in driving some dissolved ozone from aqueous solution into the surrounding air. Consequently, ozone is considerably more effective at lower temperatures (cold water = ambient temperature water) because of its increased stability and higher solubility the lower the water temperature.

It is a fallacy that ozone can be used as the sole laundering chemical, replacing all traditional chemicals. However, by incorporating ozone into the laundering process, some traditional chemicals can be eliminated, and at times the amounts of other chemicals can be reduced.

For example, alkali chemicals are added traditionally to elevate the pH of the wash water to as high a pH as 11-13. On the other hand, ozone decomposes quite rapidly in water at pH levels above 9. Consequently, the overuse of alkali chemicals defeats the benefits of ozone.

Detergents work well to remove soils from cloths being laundered, and this includes soils that have been oxidized by ozone. Because ozone destroys many of the organic soil constituents, less detergent normally is required for ozone laundering.

Chlorine is used in traditional laundering for two purposes – bleaching stains and for disinfection. If stains are the primary problem with soiled laundry, then chlorine still will be required when ozone is employed, although perhaps in lower quantities. If chlorine is used solely for disinfection, then that role can be assumed by ozone.

When chlorine is used for bleaching, attention must be paid to proper pH adjustment so as to optimize the bleaching properties of chlorine. The pH should be below ~ 8 so as to guarantee the presence of hypochlorous acid, HOCl, which is the bleaching agent of aqueous chlorine. Normally this is accomplished by addition of a souring agent – an acidic formulation) to lower the pH. Softening agents then are added to counter the harsh effects on linens caused by souring chemicals.

Whenever hydrogen peroxide is employed for bleaching laundry in place of chlorine, it is important that the pH be maintained at 9 or higher. At lower pH, H_2O_2 is not as effective.

By using ozone for laundering, the amounts of several of the chemicals used traditionally can be lowered, thus reducing or even eliminating the need for softeners. In turn, less softener results in shorter drying times.

METHODS OF APPLYING OZONE FOR LAUNDERING – Chapter 7

This chapter includes a discussion of the equipment and methods for producing and applying ozone to commercial laundry machines. Ozone normally is generated by corona discharge (or plasma techniques) for commercial laundries, rather than by UV-radiation, for several reasons. With corona discharge ozone generation:

- Oxygen-enriched air will allow higher ozone production rates and higher gas phase concentrations of ozone to be produced than when feeding dried ambient air,
- Higher gas phase ozone concentrations will result in higher aqueous phase ozone concentrations in the washer,
- Higher ozone production rates means that a single (higher output) corona discharge ozone generator unit can be sized to provide sufficient ozone to service multiple washers in the laundering facility.

If UV radiation is used to generate ozone, the ozone output rates and gas phase ozone concentrations are much lower than those attainable by corona discharge. Consequently, a single UV-ozone generating unit can service only a single commercial laundering machine, at best.

Experiences with ozone laundering to date have resulted in the development of four methods for applying corona discharge generated ozone to commercial laundry machines:

1. ***Recirculation Injection*** (sometimes called "side-arm injection") (Figure 4) – whereby ozone is added to the wash water drawn from the commercial washer which then is sent to the washer utilizing a continuous loop.

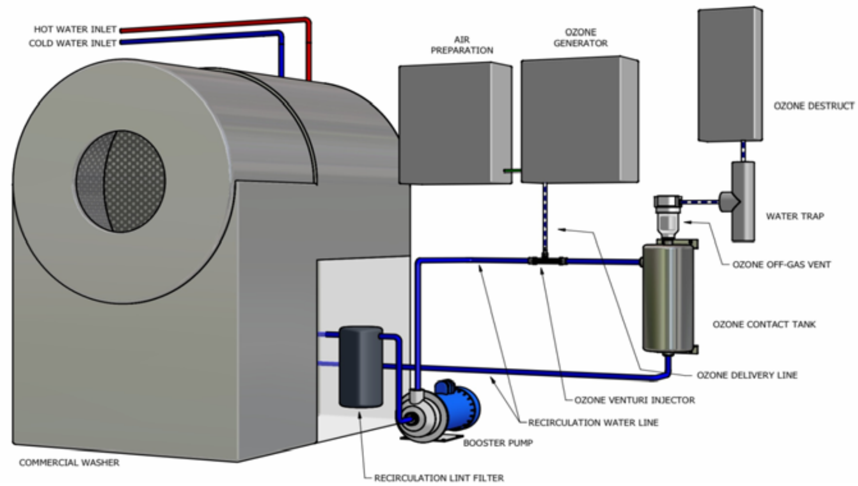

Figure 4. Schematic diagram of a typical Recirculation Injection (RI) ozone laundry system.

2. ***Direct Injection*** (Figure 5) – involving less peripheral equipment than Recirculation Injection, this method involves adding ozone directly to the water on its way to the washer.
3. ***Ozone Charge*** (Figure 6) – similar to Direct Injection, but involving either a water storage tank operated at atmospheric pressure, or with the system operating at a positive pressure and without the water storage tank;
4. ***Ozone Diffusion*** (Figure 7) – in which gaseous ozone is added directly to the water inside the washer through a special diffuser.

The first three techniques each involves injecting ozone into water that is outside of the washer, then passing the ozone-containing water into the washer. During washing, no additional ozone is added except what enters when ozone-containing water is added either for washing or for rinsing.

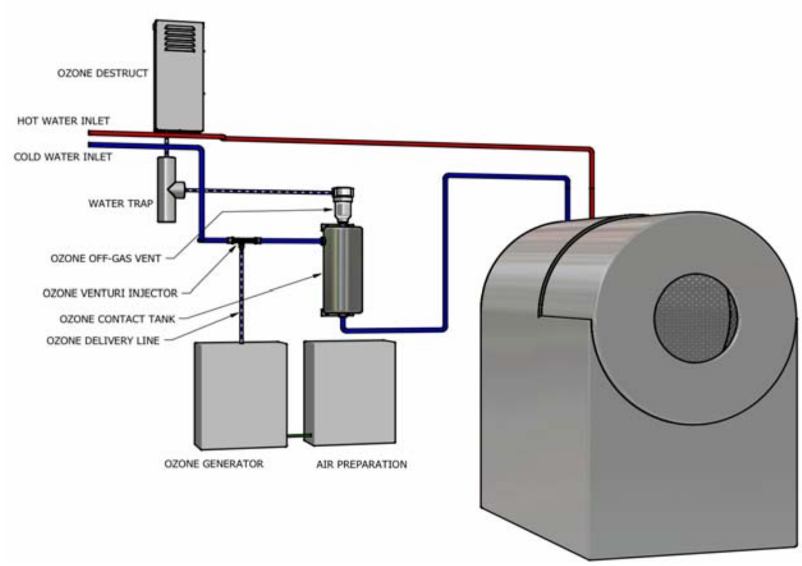

Figure 5. Schematic diagram of a typical Direct Injection (DI) ozone laundry system.

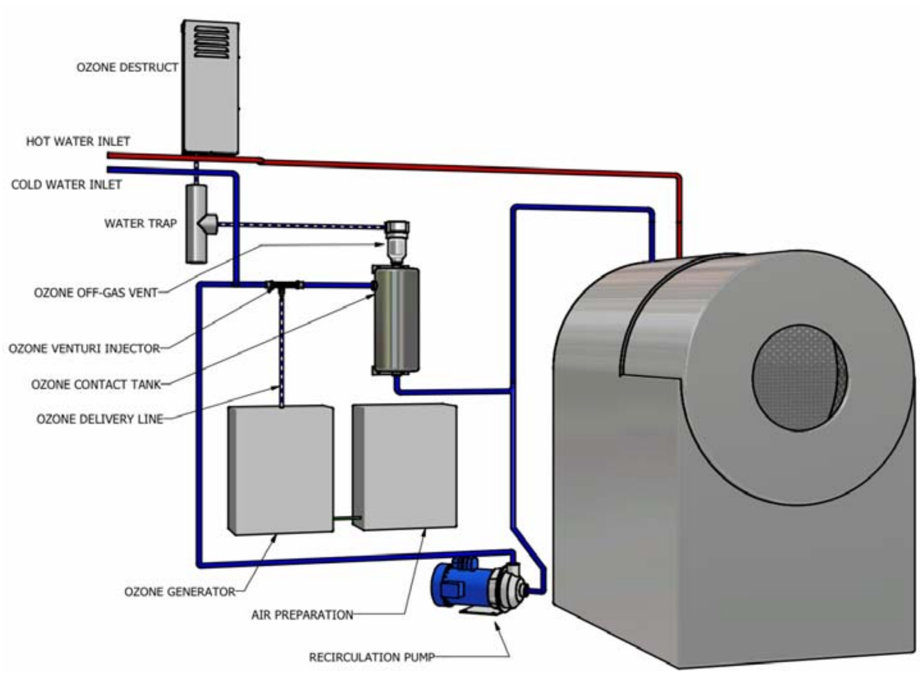

Figure 6. Schematic diagram of Pressurized Ozone Charge System.

This last procedure, Ozone Diffusion (diffusing ozone directly into the washer itself – Figure 7), enables constancy of the desired dissolved ozone levels inside the washer at all times during all laundering cycles. In addition, the rate of ozone production and addition is controlled and automated by monitoring the gas phase ozone concentrations within the washer itself.

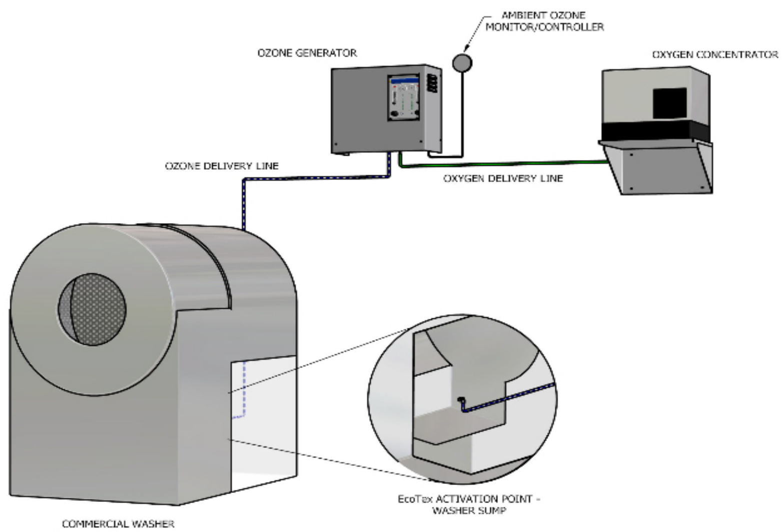

Figure 7. Schematic diagram of the Ozone Diffusion method of ozone laundering.

Ozone in both the aqueous and gas phases is desired in the washer since some of the gaseous ozone is folded into the linen's being washed, and this helps to loosen and remove linen soils. It also allows linen-carried microorganisms and contaminating organics to be attacked by ozone in both aqueous and gaseous phases.

The Ozone Diffusion system is considered to be the current state-of-the-art method of ozone laundering because ozone is added continuously to the washer after the water level is reached in the washer. Thus residual ozone levels in the wash and rinsing waters remain at higher concentrations and for longer time periods than are attainable by the first three procedures.

Figure 8 shows plots of residual ozone in washer waters over 15 minutes of laundering as provided by an Ozone Charge system compared with an Ozone Diffusion system [12]. Clearly, the Ozone Diffusion system provides a higher and more constant level of dissolved ozone for the totality of the laundering cycle time (~15 minutes).

A recent modification to the Ozone Diffusion process has been made by AWOIS LLC, located in Auburn, New Hampshire. A gas phase ozone analyzer monitors the level of ozone in the air space above the water level inside the washer. This Aquawing analyzer/monitor also controls the output of the ozone generator so as to maintain a relatively constant 1.0 ppm gaseous ozone level in the washer air. In turn, this relatively constant level of gas phase ozone in the washer air controls the amount of dissolved ozone in the washer water. The Aquawing system also has a VO3 (validated ozone) box with a light that turns on when a preset time has been reached. In turn, this also validates that dissolved ozone is present in the wash wheel water, thus ensuring the achievement of microbial disinfection.

Figure 9 shows the effects of such ozone gas phase control in the washer air and in the washer water.

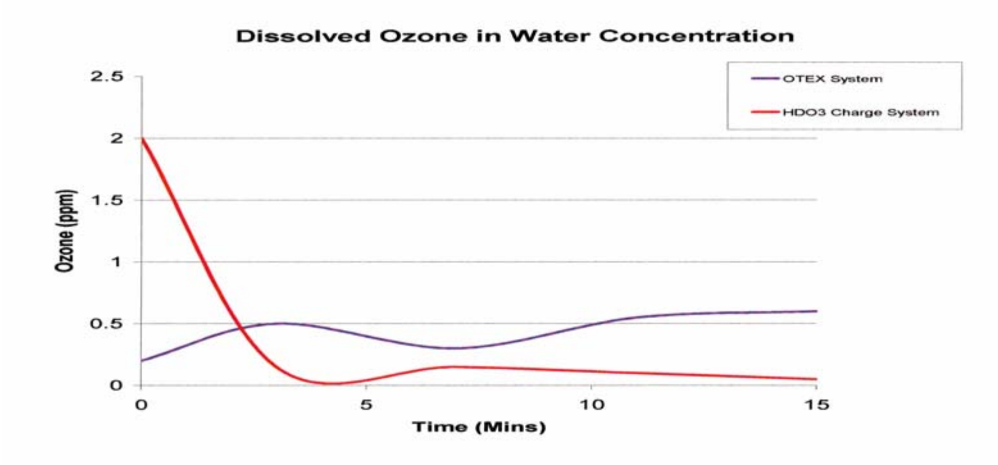

Figure 8. Dissolved ozone levels by Ozone Charge vs Ozone Diffusion techniques [10].

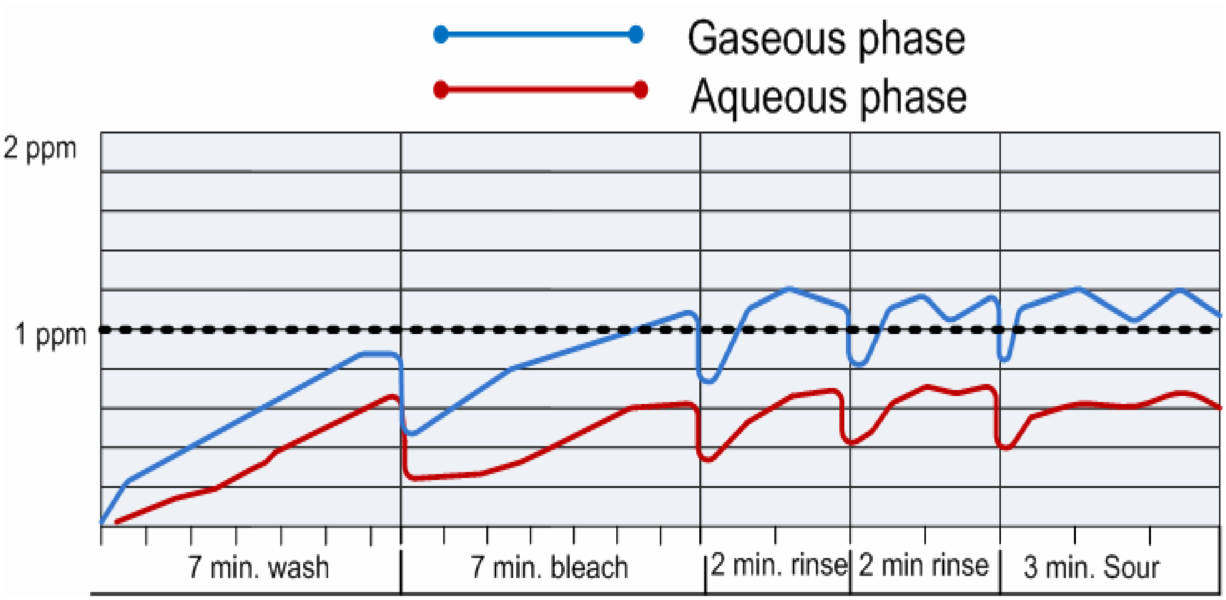

Figure 9. Ozone in aqueous and gaseous phases in an Ozone Diffusion washer. Ozone in gas phase controlled by means of an Aquawing ozone monitor/controller (graphic courtesy of Dave Spofford, AWOIS LLC, Auburn, NH, USA).

This AWOIS LLC Aquawing ozone diffusion (Interfusor™) washer with ozone being monitored and controlled in the washer gas phase has been approved and specified for use in the State of Missouri, based on several years of commercial ozone laundering successes in 15 Missouri correctional facilities (William Kimmel, R.J. Kool Co., No. Kansas City, MO, private communication, May 19, 2010). The Aquawing system also has been approved for use in commercial laundries in the State of New Hampshire (Ralph Daniels, AWOIS LLC, Auburn, NH).

Adding ozone directly to the washer drum not only ensures the appropriate dissolved ozone level, but as the laundry is being agitated with ozone-containing water, there is considerable gaseous ozone that is repeatedly folded into and throughout the linens or other materials being laundered. Thus the targeted microorganisms and laundry soils are constantly in contact with ozone at all times, thus making the functions of ozone even more efficient than by other methods of ozone addition.

OPERATOR TRAINING AND OZONE SAFETY – Chapter 8

Whenever equipment that is new to the owner and staff is installed for any application, a period of time is necessary for staff to develop a comfort level with that equipment. Ozone and its peripheral equipment is new to the laundry industry and the new user of ozone must understand what this material is, how it is made and applied, and how to know when the equipment is not performing as it should, and then what to do to rectify the situation.

The lay public is bombarded many times during the year with media announcements such as "the ozone level in the ambient air is high, therefore certain classes of citizens should be careful about venturing outdoors." Another common negative announcement is "the hole in the ozone layer is widening, thus allowing harmful high energy UV radiation to reach the Earth's surface."

All of this plus EPA, FDA and OSHA regulations for ozone in the air makes it clear that humans should not breathe ozone, because above regulated ambient air concentrations, that air can cause detrimental health effects to humans breathing it. This chapter addresses these topics.

Operator Training for Ozone Laundering

There are three approaches to the operation and maintenance of equipment that is new to the user:

1. Do it yourself – select one or more staff members and have them trained by the equipment supplier,
2. Set in place an operation and maintenance service contract with the ozone laundering equipment supplier that requires the equipment supplier to operate and maintain, or
3. Effect some combination of approaches #1 and #2.

Doing it yourself (approach #1) usually is cost-effective for the larger laundry systems that already have access to at-hand maintenance staff and laundry operators. Approach #2 is effective for smaller laundry systems that do not have ready access to full-time maintenance staff and laundry operators.

Approach #3 normally is the most cost-effective of the three. Usually, suppliers of ozonation equipment offer a break-in period following installation and startup during which one or more operatives of the equipment supplier are on-site to be sure that all items have been installed correctly and are operating properly. During and preceeding this startup period (on the order of 14-30 days) laundry operators and their maintenance staffs are taught the ins and outs of their new ozone equipment operation. These ins and outs include developing the "feel" of the ozonation system – when it is operating properly, what problems may arise and how to address them, and when to recognize that an item of ozone equipment is not operating properly, in which case the supplier should be contacted.

Equipment for commercial ozone laundering usually is sold and installed by firms that also sell and install traditional types of laundering equipment. These are the people that usually service traditional equipment, and also can service the ozonation equipment when it is part of their product line.

For example, the firms JLA Ltd. (United Kingdom) and Daniels Equipment Company (USA) have fleets of service trucks operating in all regions of the UK and USA, respectively. Staffs of their customers are trained to operate their ozone laundry systems on a day-to-day basis. If any problem arises, a call to either firm fetches a service truck within a few hours to solve the problem.

Safety of Ozone Laundering

An important and common inquiry for any prospective ozone laundry system user is the question of safety. Ozone systems can be operating in small rooms with laundry personnel in close proximity to the ozone generator(s). Since it is well-known that ozone is a powerful oxidizer and causes disagreeable responses to persons breathing it (coughing, wheezing, nausea, shortness of breath, etc.) above certain concentration and exposure levels, the safety of the use of ozone in a laundry operation is a valid and important concern.

People come in contact with ozone every day in the air we breathe (produced via ultraviolet radiation from the Sun reacting with air pollutants) and with equipment such as photocopiers and electrical motors which can produce ambient air ozone concentrations as high as 0.5 ppm. Naturally occurring ozone levels can reach as high as 3.0 ppm in heavily urbanized areas [13].

On the other hand, during more than 100 years of varied commercial applications (i.e., drinking water, wastewater, swimming pools, etc.), the safety record of ozone is unsurpassed. ***No fatalities ever have been linked to exposure to ozone anywhere in the world as a result of its generation and application.***

This incredible safety record of ozone is attributed largely to the fact that those who manufacture ozone generators and ozonation equipment recognized early on that the strong oxidizing and disinfection properties of this unique gas must be controlled. Users of ozone and ozonation equipment must not be exposed to ozone that might leak or escape from the enclosed environments of its production and application.

To this end, responsible suppliers of ozone generating and application equipment also supply ozone sensors and monitors to control the processes occurring inside both the ozonation system as well as inside the laundry washing equipment. These analytical devices sense and quantify the levels of ozone in gas and aqueous phases of any application of ozone. Some of these devices control the operation of ozone equipment in a laundry, calling for the ozone generator to produce ozone and dissolve it up to a predetermined concentration in the washer water. These same devices also automatically turn down or shut off the output of an ozone generator so that excesses of ozone are not produced.

Because ozone is only partially soluble in water, there will always be some ozone escaping from the water during gas/liquid contacting and washer drum agitation. One control option is to pass this "off-gas" containing ozone through an ozone off-gas destruction device, which converts ozone into oxygen (from which ozone is produced), and this harmless gas is discharged to exhaust. These ozone monitoring and control approaches ensure that operating personnel in laundry facilities are not exposed to ozone above OSHA-regulated levels (0.10 pp, time-weighted average over an 8-hour day; or 0.30 ppm over 15 minutes, not to be exceeded more than four times daily) at any time.

As an additional control option, another type of gas-phase monitor/controller is installed in the laundry room to sense and control the accidental discharge of ozone from (possibly) leaking piping or connections. If the ambient ozone level inside an ozone laundry were ever to rise to the OSHA Permissible Exposure Limit of 0.10 ppm (time-weighted average over an 8-hour working day), the ozone monitor/controller can be programmed to first sound an alarm, turn off the power to the ozone generator (thus ceasing any subsequent generation of ozone until the cause of the ozone leakage has been determined and corrected, and (3) then start up room exhaust fans. All three actions occur in rapid-fire succession.

These precautionary safety procedures for ozone were developed decades ago and have been operating successfully in commercial ozone applications all around our world.

Commercial laundry codes normally require 10 air changes per hour in laundry rooms – which means that once every six minutes, laundry room air is changed. In and of itself, this requirement ensures than extraneous ozone in laundry room air will be exhausted every six minutes, thus guaranteeing that OSHA's Short Term Exposure Limit for ozone (0.30 ppm ozone over 15 minutes) will never be exceeded, and also ensuring that OSHA's Permissible Exposure Limit (0.10 ppm, time-weighted average over an 8-hour day) should never be exceeded, even in the event of a catastrophic accident to the ozone delivery system, in which case the power to the ozone generator will be terminated, thus terminating the generation of ozone.

OZONE LAUNDERING FACTS AND FALLACIES – Chapter 9

This chapter deals primarily with the misunderstandings about ozone as applied to laundries. As happens many times, when ozone began to show promise in laundering, those who knew something about ozone but little about laundering, made many overclaims for ozone in their zeal to make a sale. Oftentimes that situation was exacerbated by zealots new to the ozone field as well as to laundering. As a result, many fallacious statements and claims about ozone were circulated initially that were not supported by later performances.

Other fallacious statements decrying ozone's usefulness in laundry systems have been made by conventional laundry personnel whose products are being displaced by the newer ozone-laundering systems.

The authors list many of these fallacies and then counter them with known scientific facts.

THE FUTURE FOR OZONE IN LAUNDERING – Chapter 10

There is little question that ozone laundering has a very bright future. Not only does the use of ozone in ambient temperature water ensure the killing/inactivation of microorganisms, including MRSA, *C. difficile*, and viruses within six minutes of the initiation of laundering, but this remarkable result is attained at approximately half the total cost of traditional methods of laundering that do not utilize ozone. Additionally, discharging laundry wash waters to publicly operated wastewater treatment plants or to rivers, lakes or streams actually provides environmental benefits to these receiving waters (because of increased oxygen contents).

Several different approaches to the addition of ozone to laundry systems have been developed. The most recent, the Ozone Diffusion method in which ozone is diffused directly into the washer itself, is the most effective since the concentration of ozone in the wash water can be better monitored, controlled and stabilized by this approach. By this technique of adding ozone to the washer drum also provides the benefits of exposure of the laundry to gaseous ozone as well.

Modern methods of generating ozone by corona discharge from high oxygen concentrations in dried air now allow a single (higher output) ozone generating system to service multiple laundry washers at the same or at differing times. On the other hand, the current costs for such single-generator-multiple laundering machines need to be reduced.

For home laundering, an application so far unapproached (as far as the authors are aware) small-scale corona discharge ozone systems are available. However, UV-ozone generators also are available which might prove to be appropriate for this application at lower cost because UV-ozone generators do not require air treatment. For UV-ozone systems to be successful in the home laundry market, however, performance and design data need to be developed, so that interested users can have confidence in this potential approach to home laundering.

A current barrier to mass acceptance of ozone for laundering is the reticence of regulatory authorities to modify the current mandatory use of high temperatures which (unknowingly) exclude the use of ozone. At elevated temperatures ozone decomposes rapidly, providing no disinfection or oxidation benefit. Regulators should stand ready to accept credible scientific studies that prove the performance of ozone for laundering under the conditions determined in such studies.

On the other hand, the recent approvals of ozone laundering systems by the United Kingdom's Health Protection Agency (Department of Health) and by the States of Missouri and New Hampshire in the United States should serve to stimulate at least interest on the part of local, state and national regulatory authorities to allow impartial third-party evaluation of ozone laundering.

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REFERENCES

[1] Rice, R.G., DeBrum, M., Cardis, D. and Tapp, C. 2009, "The Ozone Laundry Handbook: A Comprehensive Guide for the Proper Application of Ozone in the Commercial Laundry Industry", Ozone: Science & Engineering,31(5):339-347.
DOI: 10.1080/01919510903091318

[2] Rice, R.G., DeBrum, M., Hook, J., Cardis, D., and Tapp, C. 2009, "Economic and Environmental Benefits of Ozone in Ozone Laundering Systems", Ozone: Science & Engineering, 31(5):348-356. DOI: 10.1080/01919510903091839.

[3] "Ozone Laundry Case Study – Apple Farm Inn, San Luis Obispo, CA", 2007, on ClearWater Tech web site:
http://www.cwtozone.com/uploads/SalesDocs/Markets/Laundry/EcoTex/EcoTex%20PPT:PPS/EcoTex%20Apple%20Farm%20Inn%20CS%20050608.pps

[4] Cardis, D., Tapp, C., DeBrum, M., and Rice, R.G., 2006, "Ozone in the Laundry Industry – Practical Experiences in the United Kingdom", Ozone: Science & Engineering 29(2):85-99; DOI: 10.1080/01919510601 186048.

[5] Scientifics Ltd., 4 Hexthorpe Road, Doncaster DN4 0AE, UK, letter report to JLA Ltd., SD/DOW07090-01, 21 August 2006.

[6] WRc-NSF Ltd., Medmenham, Marlow, Bucks, UK, May 22, 2005, "The OTEX Validated Ozone Disinfection Washing System".

[7] Ltr.dated Nov. 11, 1997, from the Hong Kong Environmental Protection Dept., to E Technologies Ltd. (Hong Kong), www.ETechnologies.com.

[8] Rice, R.G., DeBrum, M, Hook, J., Cardis, D. and Tapp, C. 2009. "Microbiological Benefits of Ozone in Laundering Systems", Ozone: Science & Engineering, 31(5):357- 368.
DOI: 10.1080/01919510903170419

[9] Hook, J., 2007b, "Degradation analysis of Microfibre Cloths Within the Healthcare Environment", JLA Report OTEX LD17, February 2007.

[10] Hook, J., 2007c, "Microfibre Condition Investigation Following Healthcare Laundry Process", JLA Ltd. Report LD28, May 2007.

[11] Reid, T., Wilson, A.W., and Galloway, D.B., 2007, "A Comparative Study on the Disinfection of Hospital Laundry Using Ozone: A 2-part Single Blind Study Using Standard Hospital Laundry Cleaning Techniques versus the OTEX Validated Ozone Disinfection System, Final Study Report, Protocol No. Ozone/01-2007/120207/Hospital Laundry Study, Version 6, 22 June 2007.

[12] Hook, J., 2005, Bacteriological Investigation: OTEX Laundry System Solution Test, OTEX Report No. LD01, Sept. 2005, JLA :td., Meadowcroft Lane, Ripponden, West Yorkshire, HX6 4AJ, United Kingdom.

[13] Water Quality Association, 1997, *Ozone for Point-of-Use, Point-of-Entry, and Small Water Treatment Applications – A Reference Manual*, J.F. Harrison and P. Blazek, Editors (Lisle, IL, USA).