Advances in the application of Ultraviolet light for swimming pool disinfection.

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Introduction

Ultra violet (UV) light has gained rapid prominence as an effective disinfection technique, and was introduced into swimming pools in the UK in the mid 19990's. Early attempts to use UV had involved the combination of UV lamps and Infra Red emitters; the UV was to disinfect the organisms in the pool water and the IR emitters designed to destroy the combined chlorine species. The lack of full flow capacity, and high cost led pool operators to migrate towards ozone systems, which promised much. Ozone remained a preferred technique for several years, however high initial capital cost, coupled with ageing and complex plant requiring continuous attention led operators to re-examine UV light. The arrival of powerful medium pressure lamps, capable of treating a full recirculating flow, coupled with automated wiping and lower overall operating costs led to the replacement of ozone by medium pressure UV systems. Today several thousand pools use UV as a method of disinfecting the "emerging" (chlorine resistant) organisms, and effectively eliminating the combined chlorine nuisance.

The problem

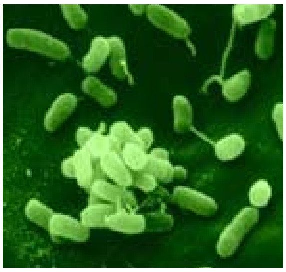
Bathers need to be kept safe, and pool operators also want to make the experience as pleasant as possible, whilst balancing the commercial needs of their business. Traditionally chemicals such as chlorine have been added to pools to provide effective disinfectants; this has worked well however organisms have started to develop resistance to chlorine, and several outlined later in this article cannot be killed using chlorine alone. New developments in pool disinfection use electrolysis to form chlorine in situ by making the entire pool into a very low concentration brine solution. This seems to be a safer method of chlorinating the pool, and is gaining acceptance.

A secondary issue for the pool operators are the by-products formed by the addition of chlorine to pool water; combined chlorine species are irritants, cause corrosion and are increasingly liked by many research groups to asthma in children and elite athletes.

The risk of infection

People swimming in pools, using splash pads for recreation, or visiting indoor or outdoor water parks are at risk from waterborne infection. Some of these infections are naturally present on skin, in hair, noses, mouths, intestinal and uro-genital tracts. The vector for transmission is both the water and pool surfaces. The adoption of UV light should not be seen either to replace the dosing of chlorine, or indeed to replace good pool hygiene practices. The UV systems serve a dual role; primary disinfection of the waterborne organisms, and effective photolysis of the combined chlorine species.

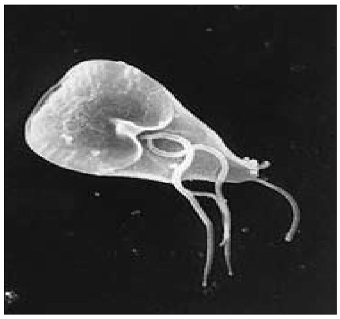
Pseudomonas aeruginosa is probably the most common of pool organisms. This species is demonstrating increased resistance to chlorine, particularly in spas or hot tubs.



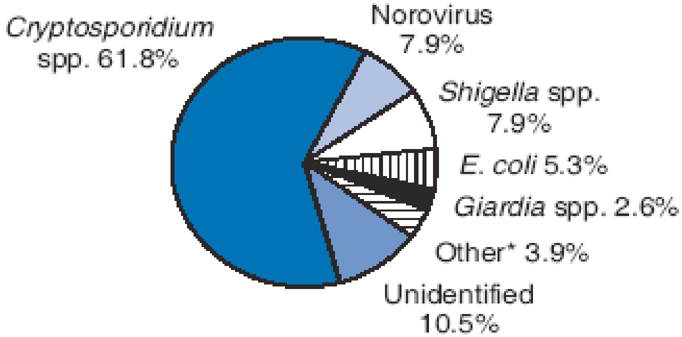
Staphylococci is another bacteria that is demonstrating resistance to chlorine, and are often isolated from pool water samples because they are naturally occurring in the ear, nose and on skin.

Some of the protozoan pathogens such as Cryptosporidium and Giardia have developed complete resistance to chlorine. They are excreted by infected swimmers during fecal events, and a carrier state exists where those infected show no obvious symptoms. The outbreak of Cryptosporosis from a drinking water plant in Milwaukee in 1993 effected over 400,000 people who drank the water, and caused over 100 deaths.


Cryptosporidium


Giardia Lamblia

Other protozoans include Naegleria Fowleri, which is a pathogenic amoeba that causes the fatal disease primary amoebic meningo-encephaltis. The organism enters the human brain thru pool water inhaled thru the nose. Several viral species are isolated from swimming pools, and Enterovirus is often found in wading pools. This species causes gastroenteritis. Adenovirus infection produces a sore throat, fever , diarrhea and occasionally conjunctivitis. The Herpes simplex virus is spread by bathers with cold sores, and can survive for extended periods in warm humid conditions.



The graph above is a summary of the threats to swimmers; Cryptosporidium is the single most common species occurring is outbreaks in recreational pools in the USA in the period 1995 to 2004.

Eliminating combined chlorine

The strong, acrid chlorine smell associated with swimming pools and spas is actually the combination of chlorine with compounds introduced into the pool , often by bathers themselves. Bathers introduce urine, sweat, hair, suntan oil and other organic compounds into the pool. These react with the chlorine to form nitrogen trichloride, chloramines, trihalomethanes, chloroform, halogenated hydrocarbons and aldehydes. Many research groups have studied the effect that exposure to these chemicals has, for a wide range of target groups. 11% of swimmers at the 1984 Olympic games recorded some degree of asthma rising to >20% by 1996, and 25% of the US Olympic swim team by the 2000 Olympics in Australia.

Thickett et al in 2002 (2) investigated the effects that breathing chloramines has on indoor pool workers, and noted that the pool workers asthma symptoms resolved significantly when placed away from the pool environment. A study of healthy school children , undertaken by Carbonnelle et al in 2003 (3) showed that exposure to chloramines significantly increases the permeability of the lung epithelium , similar to the lungs of smokers.

In 2008 Bernard (4) published research findings from a study of chloramine exposure from outdoor pools, concluding that there is a marked increase in asthma caused by attending outdoor pools. Outdoor pools were thought not to be a source of chloramine irritation, and in 2009 (5) a study of epithelial damage in elite athletes was published by Carlson et al.

Likewise Bougault (6) studied asthma, airway irritation and epithelial damage in swimmers and observed airway hyper-responsiveness in 69% of swimmers.

Other effects of chloramines can include corrosion of the pool structure. The volatile chloramines carry chlorine species to condensation in parts of the building remote from the pool. Repeated evaporation causes these species to concentrate , causing both safety critical damage and area degradation. Stress corrosion cracking of roof supports, wire suspensions and bolt heads can lead to catastrophic failure. Pool ceilings collapsed at Steenwijk (Netherlands) in 2001, and in Uster (Switzerland) in 1985.

Air treatment systems can play a role in reducing the transit of the chloramine species, however this approach is not a root cause solution.

Chloramines are linked to pin hole failure of copper pipe, however the phenomena is site specific

UV systems are used to both disinfect the pool water, and also to break up or photolyse the combined chlorine species. Most of the systems in use in pools globally are medium pressure systems, as this type of lamp produces many different UV wavelengths, and hence are sometimes called polychromatic lamps. Low pressure lamps are sometimes referred to as monochromatic lamps as they produce a single UV wavelength at 254nm.

Collapsed pool ceiling in Holland caused by stress corrosion cracking.

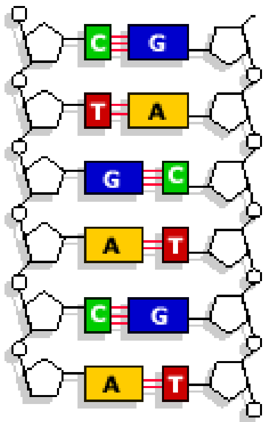
Copper pipe pin holes caused by a switch to chloramines Photo Marc Edwards, Virginia Tech.

The role played by UV light.

Disinfection

UV light has the ability to destroy the cross bonds in the DNA contained in the nucleus of an organism (or RNA in the case of a virus). UV light between the wavelengths 230nm to 300nm are absorbed by DNA, and this energy causes the cross bond to rupture. This process is called dimerization. Technically the organism is not killed by the UV light, rather the damage caused to the DNA denies the basic cell function of replication, respiration and the assimilation of food. Without this ability the organism quickly dies.

A number of researchers including Oguma et al (7), Zimmer and Slawson (8) and Hu (9) have now shown that organisms exposed to a comparable dose of UV light from a low pressure lamp are able to repair the damage to their DNA, a phenomena called photorepair. Two repair mechanisms have been observed; light repair (triggered by enzymatic stimulation) and a slower dark repair. The light repair process uses an enzyme called photolyse to repair the damaged DNA. Photolyse is stimulated by sunlight, and this explains why medium pressure systems are usually selected for open air water parks, where water will be exposed to sunlight after disinfection, and also for waste water reclaim applications, where highly polished wastewater is stored underground as part of an Aquifer Storage and Recovery process. Photo-repair does not occur after exposure to medium pressure UV light, as significantly more damage is caused to the DNA structure, too much to permit any possible repair.



UV light is absorbed by the red cross bonds, causing them to rupture and dimerize the DNA

No organism is able to develop resistance to UV light, and the market leading companies such as ETS, LLC, atg UV (in the UK) and Trojan Technologies have now complied databases to quantify what level of exposure to UV light is required to achieve a predictable level of deactivation.

UV dose is measured as m J cm-2 . Many of the nuisance organisms that have developed profound resistance to chlorine (it would take 15,300 minutes or 10.5 days for 1mg/litre of free chlorine to achieve 99.9% removal of Cryptosporidium at pH7 and a temperature of 25 degrees c); Cryptosporidium Parvum is simple to deactivate using UV light.

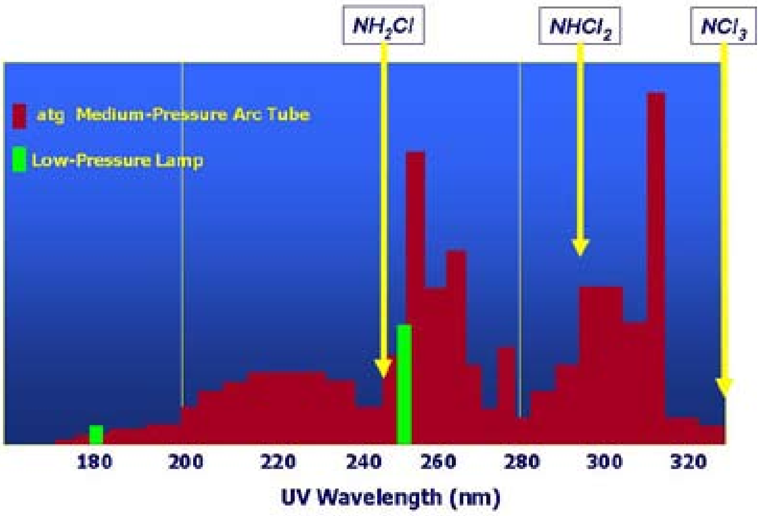
System sizing is a function of determining three variables; flow rate, what organisms are likely and the transmittance of the water. Several factors can effect the transmittance of the water, including turbidity, suspended solids and color. Variations in these parameters are undesirable for recreational water. Several UV companies have undertaken system validation using non pathogenic surrogates such as MS-2 phage to verify actual performance using a third party test house , and to properly understand the capacity of the machines. New York state requires that all UV systems are independently validated in accordance with strict protocols.

UV system undergoing performance validation for use in New York State.

Photolysis

In the same way that specific UV wavelengths are absorbed by DNA, leading to bonds rupturing, so other specific wavelengths are absorbed by mono, di and tri chloramine. When these wavelengths are absorbed, the energy they carry breaks the chemical bond, and a breakdown process is initiated.

Monochloramine (NH2Cl) species absorb UV light at 245nm. Dichloramine (NHCl2) species absorb UV light at 297nm, and Trichloramine (NCl3) species absorb UV light at 340nm.



Medium pressure (polychromatic) lamps produce these wavelengths in abundance, however as low pressure lamps only produce a single UV line at 254nm, they are not well suited to use for the specific removal of the nuisance chloramine species.

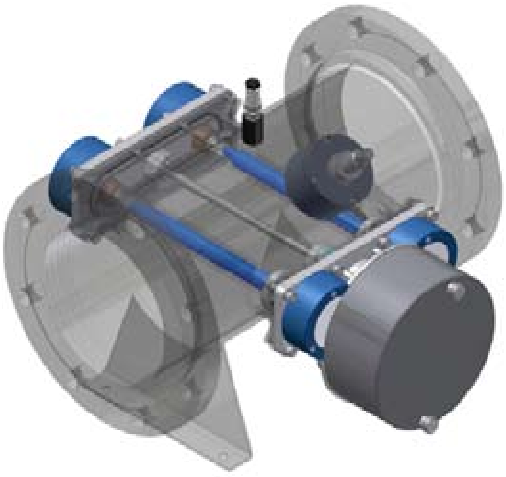
A UV dose of between 40 to 60 m J cm-2 is normally applied for the removal of chloramine species, and sizing factors include pool size, turnover rate and bather load. A ratio of total : bound chlorine ≥ 4:1 can be achieved, resulting in a more pleasant bathing environment for swimmers and employees. Such a high UV dose will eliminate all of the usual pool organisms .

Operators also report improvements in water clarity, and a reduction in TDS when the UV system is in use. Most pools turn the UV off or reduce output overnight when the chloramine challenge is absent, and start the system in advance of the pool opening in the morning. Typically the UV system will communicate to the building management software using a MODBUS type connection.

ETS chambers installed at Utah Pool

Critical features

The UV lamp is contained with a quartz sleeve, and the sleeve will be fouled by iron in the water being treated. UV light will accelerate the photochemical deposition of iron onto the surface of the quartz, and will quickly occlude the optical path unless it is removed. Automated wipers are fitted to most pool systems to remove fouling from the surface of the quartz. Early system design used limit switches and magnets to locate the position of the wiper assembly, however their complexity led to them being replace with more reliable embedded pulse technology.



CAD drawing of wiper (ETS)

ETS chambers installed vertically in pool filter room

Conclusion

UV technology has an important role to play in the provision of safe, healthy water for recreational use. As more organisms become tolerant and progressively resistant to chlorine, so operators and designers will adopt this exciting technology to complement the use of conventional halogens, and reduce bathers exposure to potentially harmful chemicals.

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