

1 Introduction

Two key disinfection by-products (DBPs) in swimming pools are trihalomethanes (THMs) and chloramines (CAs), whose health impacts have been subject to much study over the years and various guidelines issued for their control (WHO, 2000). Since DBP levels in pool environments are strongly influenced by the treatment technology employed (such as chlorination or ozonation) it is of obvious interest to assess these technologies with specific regard to DBP formation on a common basis. No recognised protocol for testing these technologies currently exists, such that manufacturers' claims regarding the effectiveness of their products remain difficult to substantiate. Most evaluations are based on bench scale tests performed by the company and/or anecdotal evidence from pool operators. Such evidence is not always relevant or transferable due to the varying requirements and operating parameters of different pools. It is therefore essential to develop a common test protocol for the different technologies available, to evaluate the limits of this protocol, and finally to use the protocol to evaluate the suitability of using certain treatment techniques in pools.

1.1 The UK pool water industry

In 2001, there were 1770 public pools and leisure centres in the UK with a total revenue of around £488m (Mintel, 2002). Public and private pools are not only popular in the UK, where there is an estimated total of 0.16 million 'in ground' pools, as Germany and France have an estimated 0.32 million and 0.5 million pool respectively. The US is estimated to have a total of around 4.2 million pools, where the revenue from sales of the pools is as much as \$3.1 billion per annum (Pool and Spa Marketing, 2003).

Pool use by children in the UK is higher than that of adults: around 55% of children aged 5-9 visit a pool at least once a month, and at least 33% of children visit a pool at least once a week. Compared to this, it is estimated that around 36% of adults (aged

15+) use a pool at least once a month (Mintel, 2002). It is therefore the case that the greatest user group of pools is the most vulnerable.

At present, there are no UK statutory regulations regarding levels of DBPs in swimming pools. Organisations such as the UK Pool Water Treatment Advisory Group (PWTAG) and the World Health Organisation (WHO) provide guidelines based on the precept of free chlorine levels being as low as possible whilst still providing adequate disinfection. Both the level itself and the chlorine demand required to maintain this level vary between pools due to the variation in the water treatment technology applied and the bather load with which it is challenged.

The aim of the Pool Water Treatment Advisory Group is to improve the standard of pool water quality in the UK. It achieves this through undertaking and sponsoring research, the publication of advice and press releases, and monitoring and reviewing the pool water sector in general. The group was set up in 1984, when the Department of the Environment Sub-Committee on the Treatment of Water in Swimming Pools ceased to meet. The group is an independent committee of members drawn from a wide range of bodies, such as voluntary groups, private companies, professional bodies and statutory agencies. The group has published two swimming pool treatment advisory manuals, the first of which '*The Pool Water Guide*' was published in 1995 and the second (a fully revised edition of the first book) entitled '*Swimming Pool Water, Treatment and Quality Standards*' published in 1999.

Key sporting bodies in the UK which also play a regulatory role are the Institute of Sport and Recreation Management (ISRM) and Sport England (originally the English Sports Council). The ISRM exists to promote the provision of recreation facilities for public use to encourage participation in sport in general. It operates a National Pool Safety Award, which provides a framework for promoting high standards of pool safety and the recognition of good practice. It is a voluntary scheme and is open to all swimming pools in the UK. Sport England is responsible for developing a framework

for the country's sporting infrastructure and for distributing Lottery funding to deliver the Government's sporting objectives.

Pool safety is ultimately regulated under the Health and Safety Act via the Health and Safety Executive (HSE). However, no formal statutory UK standards are set for pool water quality by the HSE.

1.2 Previous research at Cranfield University

The 1/7th linear scale swimming pool test rig that has been used in this research was originally constructed in 1997 under the supervision of PWTAG. It has previously been used in research in 2 other projects, the details of which can be found in Black (1997), Judd and Black (1999) and Darke (1999). The existing rig is still in use, and modifications were made for the reported research project, all of which are detailed in *Materials and Methods* (Section 5).

Results that have recently been reported (Judd and Black, 2000) for a pilot-scale pool in which all operational parameters, including the dose of body fluids from bathers, were controlled. These data suggested that THM and chloramines levels are:

- sensitive to the bromide concentration in make up water
- vary slightly with pH between ranges of 7.2-7.8
- vary greatly with the synthetic bather load dose, as provided by an analogue of key body fluid constituents, and
- sensitive to intermittent dosing

More significantly, a simple mass balance (from pool water analysis only) performed by the authors revealed that a large proportion of the carbon, nitrogen and chlorine was unaccounted for. It was speculated by the authors that, although steady-state levels of THMs were achieved within 3 days, accumulation of both chlorinated and unchlorinated organic matter may be taking place in the pool or being lost to the atmosphere, for example as THMs in the case of Cl and C.

1.3 Aims of research

The aim of this research was to provide representative data for DBPs arising in swimming pools under different operating conditions and more advanced technology. Specific objectives were to:

- a) mimic real pool conditions in the test pool, and establish a protocol for evaluation of swimming pool treatments
- b) use this protocol to evaluate swimming pool technology such as UV and ozone-GAC
- c) calculate a comprehensive mass balance across the pool system

Achieving these aims would allow a more comprehensive, and in many ways unique, understanding of the behaviour of certain DBPs in a recirculating system. This knowledge could not only be used to better understand the complex nature of DBP formation and equilibrium at a basic chemistry level, but also to benefit the public by improving conditions in swimming pools by identifying optimum dosing conditions. In this case 'optimum conditions' refers to the minimisation the concentration of harmful and/or nuisance DBPs whilst maintaining a low pathogenic risk to swimmers. In the current study the same test pool as that of Judd and Black (2000), which employs treatment processes applied in an average municipal swimming pool, has been used to conduct a more rigorous analysis in which additional water quality determinants have been measured and a modified bather load analogue used. In addition to sampling for THMs and CAs, (monochloramine (MCA) and dichloramine (DCA)), the latest tests have included measurement of total organic carbon (TOC), total carbon (TC), nitrate (NO_3^-) and total Kjeldahl nitrogen (TN). As with the previous study, the bather load was replicated using a body fluid analogue (BFA) to represent endogenous species in urine and sweat, but in this latest study humic acid (HA) was added to replicate soiling. However, the more extensive analysis has allowed a much more rigorous mass balance to be conducted and added significantly to knowledge regarding the fate of the protagonist elements in the system.

2 Swimming pool treatment

2.1 Pool water treatment requirements

People go swimming generally for exercise or relaxation. The expectation is that the pool water will have no strong odour, appear clean and be safe to use. Although the swimmer may value water which is low in odour and high in clarity over other qualities, the main concern of the pool operator is that the pool is safe. To make a pool 'safe' the water has to be clear (so that the base can be seen) and low in pathogenic microorganisms.

Swimmers contribute many chemicals, dirt and micro-organisms (most of which are naturally carried on the body) to the pool water every time they use the pool. It has been estimated, for example, that the addition per bather on first immersion in the pool is between 50 and 600 million bacteria (Powick, 1989). Some of these microorganisms have the potential to be harmful if swallowed by another swimmer and so must either be removed from the water or inactivated substantially by disinfection. Disinfection is usually achieved by using a chemical oxidant, or else some other chemical with disinfection capabilities, that is dosed into the pool water to leave a long lasting safe residual (to last until the pool has had time to recirculate the disinfectant from the dosing pump). This allows local disinfection to occur within the pool water and thus provide constant protection for the swimmer. Disinfection achieved by other methods such as ozonation or UV irradiation are 'point source' methods which possess no residual disinfecting powers, and therefore provide no local disinfection within the pool. Chemical oxidants, however, can also react with the organic matter introduced into the pool by bathers to form disinfection by-products (DBPs), some of which have health impacts (Section 3.7).

Particulate matter that is introduced by pool users also has to be removed, and this is usually achieved by filtration. The temperature of the water, of the air above the pool (in any indoor municipal pool) and also the pH must all be regulated to maintain a level of bather comfort and, in the case of pH, a disinfection capability.

2.2 Basic swimming pool water treatment

2.2.1 Water and air circulation.

A pool circulation system must allow polluted water to be removed from the pool and treated water to be re-circulated as efficiently as possible. The time that it takes for one volume of the pool to pass through the treatment system under ideal plug flow conditions is called the turnover period. The circulation rate of the pool is the volume of water in the pool (m³) divided by the turnover period (hr). This rate can be determined for a specific pool by using the following formula:

$$\text{Circulation rate (m}^3\text{/hr)} = X \text{ bather load (bathers/m}^2\text{)} \quad \text{Equation 1}$$

where X partly determines the equilibrium pollutant concentration in the pool and is normally assigned a value of 1.7 (PWTAG, 2000).

An increase in bather load will increase the concentration of pollutants in the pool that will readily react with chlorine which will temporarily decrease the free chlorine concentration in the pool. The circulation rate must be high enough to be able to pump free chlorine from the dosing tank to all parts of the pool before it has been depleted.

Adequate circulation in a pool is only achieved if the filtration plant is of sufficient size and the circulation design is suited to the type of pool being considered. Pools with complicated designs, such as those with slides and spas, must be designed with no 'dead spots' where polluted water can reside for extended periods. The turnover period for a conventional public pool (25 m long, 2 m at deep end, 1 m at shallow) is 2.5 to 3 hours. Pools with features and spas, however, require a much faster turnover. For example, spa water should have a turnover period of 5 to 15 minutes and waterside splash pools a period of 30 to 60 minutes (PWTAG, 1999).

The sequence of circulation and draw off from different parts of a pool can be varied with bather load and change in usage (for example addition of ancillary items such as

slides). As most particulate matter in the pool tends to float, a surface draw off is nearly always employed as part of the pool treatment. The minimum proportion of surface draw off in a conventional pool is 20%. This figure may rise as high as 80% in a pool with heavy bather loading.

Surface water draw off is generally achieved by one of three methods, depending on the age and use of the pool. Modern pools usually have a level deck system in which the pool water is continually lapping over the side of the pool. This water is then collected in grated drains and returned to the balance tank for treatment (Section 5). In a conventional older style pool, an overflow channel in the pool wall situated about two inches below the deck level allows water to flow into the channel/sill where it is carried away via drains to the circulation pump. The third method, generally acknowledged as being least effective, is to use skimmers. These are installed around the pool side and act as weirs which can be adjusted to variations in water depth due to high or low bather load.

2.2.2 Filtration

The turbidity of pool water must usually be lower than that of drinking water, as visibility through the water must be sufficient for a lifeguard or swimmer to be able to clearly see the base of the pool. A target upper limit of 0.5 NTU is quoted for UK pools (PWTAG 1999), compared with 4 NTU for drinking water. The pool water turbidity is generally maintained by sand filtration operated at high (31-50m/hr), medium (11-30 m/hr), or low (<10 m/hr) rates depending on the pool size. Medium rate filters are usually used in municipal swimming pools, since they allow a high enough flow of water to pass through them to accomplish an appropriate turnover, whilst maximising the filtration efficiency. At high rates, the force of the water may cause unloading of particulate material from the filter. Low rate filters give the best particulate removal but demand large filter areas and volumes to achieve the required turnover time (PWTAG 1999).

All filters require backwashing, as the filter not only clogs but also tends to unload more at higher loading capacities. Backwashing is achieved by pumping the circulating water in the reverse direction (normally base to top) to the operating cycle so that the bed becomes fluidised and particulate material is detached from the sand. The rate of flow must be great enough to fluidise the bed but low enough for there to be no loss of media. The backwash water is allowed to run to drain so as not to re-contaminate the pool water, although recovery of this water through membrane filtration may be possible.

Using relatively fine-grained sand a pore size in a sand filter as low as 100µm can be achieved, and with progressive filtration whereby particles build up within the sand bed, the pores can be reduced even further. On the other hand the removal of fine particles and microorganisms takes place mainly by adsorption onto the surface of the sand grains, rather than by occlusion in the pores. Removal can also be enhanced by pre-coagulation if so required in pools with high turbidity. Clarification of pool water is thus similar to that of raw waters for potable supply, though the contaminants are obviously of different origin and nature.

2.2.3 Coagulation-flocculation

Coagulation removes dissolved colloidal and suspended material by destabilising it through charge neutralisation so that they agglomerate to form flocs. DBP precursors such as humic acid, a well-known THM precursor, can be removed by neutralising the negative charge of the humic group through electrostatic attraction with the metal cation formed by hydrolysis of a coagulant (Babcock and Singer (1979)). Because of their larger size, flocs are more easily trapped within the filter than the free particles and can subsequently be removed by backwashing. The degree of removal depends on the pH of the water, the coagulant chosen and the dose. Coagulation can also be used to expedite the removal of micro-organisms that would otherwise pass through the filter, such as *Giardia* and *Cryptosporidium*, both of which are resistant to chlorine during their infectious stages as cysts (PWTAG, 1999; Pontius, 1990).

The most common coagulants used are alum (aluminium sulphate), PAC (polyaluminium chloride or aluminium hydroxychloride), PASS (polyaluminium sulpho-silicate), sodium aluminate, iron sulphate and iron chloride. These all work primarily through forming a gelatinous precipitate by hydrolysis and enmeshing solids in the flocs formed, a process known as “sweep flocculation”. Dosing of these coagulants must be precisely metered so they are not over-dosed, since overdosing can destabilise the flocs as well as increasing loading on the filter to cause clogging.

2.2.4 Dilution

Dilution of pool water is essential to limit the build up of dissolved pollutants in the pool and so maintain bather safety and comfort. Pollutants may arise from the bathers themselves or else be residues from dosed chemicals or accumulation of refractory DBPs. Evaporation of the pool water increases the concentration of these pollutants further. The recommended dilution of pool water varies depending on the size of the pool and its usage. PWTAG (1999) recommend a rate of 30 litres of fresh water per bather per day. Some of this dilution arises from backwashing as the pool water is lost to drain and then replaced with fresh water.

2.2.5 pH regulation,

The pH of pool water is regulated for bather comfort and the related impact on water chemistry. For example, an increase in pH can cause precipitation of hardness ions (principally calcium and magnesium), whilst a decrease will increase the corrosive action of the water on the pool fabric. The efficiency of coagulation is also primarily governed by the pH and, amongst other things, the type of coagulant used. The primary impact that pH has is on the speciation of the disinfectant being used, which not only effects the DBPs that are formed but also the efficacy of the disinfectant as a bactericide. When using chlorine as a disinfectant, for example, bactericidal potency increases with decreasing pH due to the increased concentration of HOCl (Section 3.2).

pH adjustment is achieved by dosing with either an acidic or alkaline solution depending on the type of disinfectant being used. Sodium and calcium hypochlorite are alkaline and so require an acidic reagent such as hydrochloric acid or carbon dioxide for pH regulation. With an acidic disinfectant such as chlorine gas, an alkaline reagent such as sodium bicarbonate may be used. When using disinfectants such as chlorine gas, hypochlorite, ozone, UV, chlorinated isocyanurates and bromochlorodimethylhydantoin (BCDMH), the recommended pH range is 7.2 to 7.8 in the UK. When using sodium bromide or liquid bromine, then the recommended pH is somewhat higher, at 7.8-8.2 (PWTAG, 1999). Differences in the recommended ranges arise due to the nature of the equilibrium existing between hydrolysis products formed (Section 3).

2.2.6 Temperature control

The temperature of pool water depends upon its use, but is generally regulated to around 29 to 30°C (PWTAG, 1999). In competitive and fitness pools, the temperature can be as low as 27°C, whereas pool water temperature for use by infants and the disabled is set at around 30°C. Although a warmer pool is more comfortable for the bather, it demands greater energy use, increases the humidity (making it more uncomfortable for the users) and increases micro-organism growth. For each 10°C rise in pool water temperature the micro-organism growth approximately doubles, and thus increases the propensity for colonisation of the filters. Higher temperatures also decrease gas solubility, increasing atmospheric levels of chlorine and chloramines and so increasing the characteristic chlorinous odour. These unpleasant odours are also considered to have health impacts upon bathers and lifeguards (Section 3.7). Loss of CO₂ at higher temperatures also produces an increase in pH (Section 2.2.7). Pool air is also heated, normally to no more than 1°C above the pool water temperature so as to minimise evaporation of pool water and condensation within the pool hall. Condensation can exacerbate corrosion and cause structural damage.

Ventilation of the pool air is necessary to control the pool air quality for swimmers and pool workers whilst still maintaining draught and odour free conditions for the

bathers. PWTAG (1999) recommend a ventilation rate of 10 l/s per m² of pool hall area (both pool surface and surrounding area) as a guideline figure. In an average pool, this equates to around 4-6 changes of air per hour, depending on the pool hall height. The humidity is kept between 50 and 70%, achieved using a de-humidifier or by adding fresh air. The concentration of fresh air mixed with recirculated air should be as high as possible to minimise atmospheric DBP concentrations, although there are obvious cost implications. PWTAG (1999) recommend a minimum of 12 l/s of fresh air per pool hall occupant.

2.2.7 Disinfection

2.2.7.1 Disinfectant chemicals and processes

There are many types of disinfectants and disinfection processes available for use in both municipal and private swimming pools (Section 3.3), and these are summarised below. Results of a survey of disinfectant use in UK pools carried out by Black (1997) are shown in Table 2.1. By far the most commonly used disinfectant is chlorine in the hypochlorite form, since it is easy to use, produces a 'safe' long lasting residual in the pool water and is relatively inexpensive. Bromine-based disinfectants are only generally favoured over chlorine for use in hot tubs and spas due to lower volatility at higher temperatures and the related greater retention in agitated water of both the disinfectant and the disinfection by-products.

Table 2.1 Summary of disinfection processes and their applications

Oxidant	Example of use	Size of plant	Equipment reliability and complexity	Oxidation potential (V)
Chlorine (as Na or Ca hypochlorite)	Pools of all sizes	All sizes	Good reliability. Simple to use	Chlorine=1.36 Hypochlorous acid= 1.49
Chlorine dioxide (ClO ₂)	Pool with high bather loading	Small-medium	Good reliability. Moderately complex	1.57
Ozone	Heavily loaded pools or leisure pools	Medium - large	Fairly reliable. Quite complex	Ozone= 2.07 Hydroxyl radical=2.8
Bromine based disinfectants	All pools but especially spas and hot tubs	All sizes	Fairly simple. Requires careful dosing	-
UV	Recirculating systems, pools with high chloramines	Small to medium	Fairly reliable. Moderately complex.	-

Sources: Pontius (1990) and PWTAG (1999)

Table 2.2 % disinfectant use in UK pools

Disinfectant	1989	1997
Sodium hypochlorite	55	37
Calcium hypochlorite	19	32
Chlorinated isocyanurates	-	3
Ozone plus hypochlorite	6	14
Bromination	1	2
Ultraviolet irradiation	0	2
Other	<19	10

Results of the survey by Black (1997) (Figure 2.1) reveal that the most important issue for pool operators is water quality, with bather comfort and safety also considered almost as important. Water quality/clarity and bather comfort are issues that are likely to be noticed by bathers and so provide the major source of complaints, in particular stinging eyes due to excessive chloramines (Section 3.7).

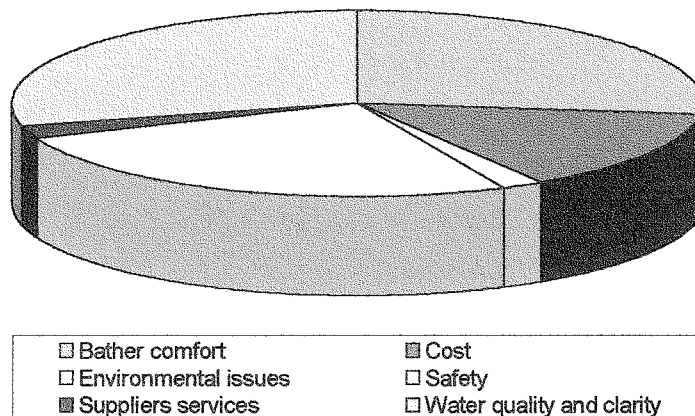


Figure 2.1 Pool operators' reasons for choice of disinfectant

Issues such as cost and supplier may be of greater importance when considering the application of more advanced technologies such as UV irradiation and ozonation. Both of these require a large power input (in particular ozone) which would increase running costs, with a further increase in cost caused by the requirement for skilled professionals to carry out maintenance. Ozone and UV are used in conjunction with chlorine to provide more intensive oxidation of DBPs and their precursors as well as enhanced disinfection, and their use (in particular ozone) in UK municipal swimming pools increased dramatically between 1989 and 1997 (Table 2.2). These processes are described in more detail subsequently (Section 4).

2.2.7.2 Kinetics of disinfection

The relationship between kill efficiency and contact time was developed by Chick in 1908 and was later modified by Watson (1908) to give the Chick-Watson law :

$$\ln (N_t/N_o) = -\lambda C^n t \quad \text{Equation 2}$$

where:

N_o = initial number of organisms

N_t = number of organisms at time t

C = concentration of disinfectant

t = contact time

λ = coefficient of lethality

n = coefficient depending on disinfectant type and pH

Substantial deviation from the Chick-Watson Law arises in practice, such that it is normal to produce logarithmic plots of C against t for fixed values of N_t/N_0 . Such plots are linear and usually have gradients close to unity (i.e. $n \sim 1$). The product of the contact time and disinfectant concentration is referred to as the Ct value which thus determines the amount of time that a certain disinfectant must be present in the system at a specific concentration to achieve a specific kill of microorganisms.

Biocidal potency is often related to pH as well as other water quality parameters such as temperature and, of course, the nature of the microorganism itself and the mode of inactivation. In the case of chlorine, Ct is strongly pH dependent due to the $\text{HOCl}:\text{OCl}^-$ equilibrium (Section 3.2) and the much greater biocidal potency of HOCl , which is known to disinfect by penetrating the bacterial cell walls and attacking the cytoplasmic layer. Ct values for removal of *Giardia* cysts in relation to log removal and pH (Table 2.3) reveal that a small pH change from pH 6 to 7.5 increases the Ct value by ~42%. Table 2.4, which shows the Ct values for the 99% inactivation of various organisms using free chlorine (from hypochlorous acid), chlorine dioxide, and ozone, shows ozone to be more effective (in terms of a lower Ct value) than both free chlorine and chlorine dioxide.

Table 2.3 Ct values for removal of *Giardia* cysts

Log removal	pH<6.0	pH 6.5	pH 7.0	pH 7.5
1	46	54	65	79
1.5	69	82	98	119
2	91	109	130	158
2.5	114	136	163	198

Source: Virginia Department of Health Waterworks.

Table 2.4 Ct values for the inactivation of organisms at pH 6-7 at 5°C using different disinfectants from Holt (1980) and EP/600/2-86/067

Organism	Free chlorine	Chlorine dioxide	Ozone
<i>E. coli</i>	0.034-0.05	0.4-0.75	0.02
Rotavirus	0.01-0.05	0.2-2.1	0.006-0.06
<i>Giardia lamblia</i> cysts	47-150	-	0.5-0.6
<i>Cryptosporidium parvum</i>	7200	79 ¹	5-10

¹ inactivation at 25°C

The biocidal potency of chlorine is generally reduced by reaction with ammonia at low pH levels. Early work by Fair *et al* (1947) on the disinfection power of chloramines revealed dichloramine to be around 60% as efficient as HOCl for inactivation of amoebic cysts after 30 minutes contact time, with monochloramine being 77% less effective. On the other hand, due to the formation of the relatively ineffective OCl⁻ ion at high pH values, chloramines are actually more efficient cysticidal agents than free chlorine above pH values of 7.5.

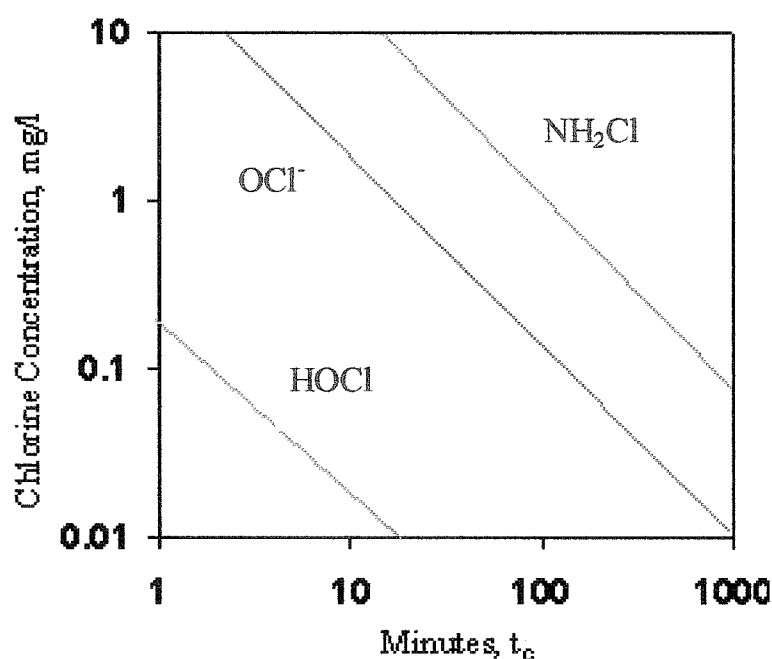


Figure 2.2 Effect of disinfectant type for 99% kill of *E. coli* at pH 7 (Reynolds 1996).

As with chlorine, the effect of ozone on different micro-organisms depends on their nature. Morris (1978) calculated lethality co-efficients for a range of organisms found in raw water supplies (Table 2.5), the specific lethality coefficient (A) being given by:

$$A = 4.6/Ct_{99}$$

Equation 3

where C is the residual concentration in mg/l and t_{99} is the time in minutes for 99% of micro-organisms destruction and 4.6 is a calculated constant for ozone. Examples of 'A' values for various organisms can be seen in Table 2.5 and actual contact times for a range of operating conditions listed in Table 2.6. It is evident from these examples that ozone is a generally more powerful biocide. In the case of poliovirus, it can be seen that for a disinfectant concentration of 1 mg/l chlorine requires a contact time of 35 seconds, whereas ozone only requires a contact time of less than 10 seconds for 99% kill. However, ozone cannot be used for local point-source disinfection since it is extremely toxic (Section 4.1).

Table 2.5 Kinetic parameters, ozone disinfection (pH 7, 10-15°C)

Organism	A	¹ C _{99,10}
<i>E.Coli</i>	500	0.001
<i>Streptococcus faecalis</i>	300	0.0015
Polio virus	50	0.01
<i>Endamoeba histolytica</i>	5	0.1
<i>Bacillus meagtherium</i>	15	0.03
<i>Mycobacterium tuberculosam</i>	100	0.005

¹Concentration in mg/l for 99% inactivation in 10 minutes

Table 2.6 Time required for 99% inactivation at 1mg/l (Pontius 1990)

Micro-organism	Disinfectant	Experimental conditions	Time required
Giardia lamblia	Free chlorine	pH 6, 5°C	~60 minutes
Giardia Murius	Ozone	pH 7, 5°C	~ 10 minutes
E. Coli	Free chlorine	pH 8.5, 2-5° C	~ 35 seconds
E. Coli	Free chlorine	pH 8.5, 20-25°C	< 10 seconds
E. Coli	Combined chlorine	pH 7, 3-5°C	~ 60 minutes
Poliovirus 1	Free chlorine	pH 6, 2°C	~ 35 seconds
Poliovirus 1	Ozone	pH 7.2, 2°C	< 10 seconds

2.2.7.3 Recommended disinfectant residuals

A residual disinfectant is needed to provide protection for swimmers against pathogenic microorganisms discharged directly into the pool water. Standards for residual disinfectant levels vary between countries and with the type of disinfectant and process being used (Table 2.7). For example, levels of residual disinfectant may be lower when using ozonation in conjunction with chlorine, since the ozonation process reduces levels of organic matter which would otherwise react with chlorine and reduce its concentration in the pool. Such variation may arise from differing attitudes to pre-swim hygiene; in Germany it is compulsory to shower before swimming which lowers the amount of pollutants introduced into the pool and thus the chlorine demand (Section 3.4).

Table 2.7 Recommended disinfectant residuals in swimming pool water (mg/l), adapted from WHO (2000)

Disinfectant	UK	EC	USA	Germany	Italy
Free chlorine ^{1,2}	1-2	-	1-3	0.2-0.6 (0.7-1 spas)	0.6-1.2
Bromine	1.5-3.5	-	2-4	-	-
Chlorocyanurates	2.5-5	-	-	-	-
Chlorine dioxide	-	0.2-0.3	-	-	0.3

¹ hypochlorous acid and hypochlorite ² as free Cl₂