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Bench-marking Pool Water Treatment for coping with Cryptosporidium

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Abstract

The frequency of confirmed incidences of cryptosporidiosis associated with pool waters has increased. *C.parvum* oocysts are removed by filtration and inactivated by the chemical treatments used but only to various levels of success. Pool operators need an easy method for assessing the ability of their treatments to deal with oocysts.

The efficacy of a pool water treatment plant depends on its original design and on its existing condition and operation. Oocyst removal by filtration depends much on the size, depth and condition of the filter media, the filtration rate and effective use of coagulation. Either ozone or chlorine dioxide treatment can produce useful inactivation especially at normal pool water temperatures. Chlorination used without other disinfectants has negligible effect in oocyst inactivation even with the long contact times. However, allied to treatment with ozone or chlorine dioxide, chlorination can make a small contribution due to synergism.

Published results by various investigators of oocyst removal or inactivation are collated and adapted to provide a method for bench-marking the robustness of pool water treatment strategies for coping with oocyst-rich incidences. Key removal and inactivation data is set out as a set of easy look-up tables that is used in conjunction with basic information operators should know about their pool water treatment systems. The information also provides pool operators with a means of identifying how they might optimise the performance of or upgrade their existing treatment strategies.

Introduction

C.parvum oocysts in Pool Water

The frequency of confirmed incidences of cryptosporidiosis associated with pool waters has increased during recent years (Foundation for Water Research, 2000; PHLS, 2000). Pool swimmers contract cryptosporidiosis through ingestion of pool water containing *C.parvum* oocysts originating in faecal matter released by other swimmers suffering, or have very recently suffered, from cryptosporidiosis.

It has been estimated that 1 ml of faeces can contain as many as 5 x 107 oocysts. If a child has a loose-bowel movement of 150 ml into a typical 25m x 12m municipal pool of about 450 m^3, this would result in an average concentration of about 20,000 oocysts/litre (20/ml). When a pool has a large number of swimmers, these swimmers will contribute to the mixing process. Therefore, a localised faecal release will become dispersed quite quickly In practice there would be pockets of water with greater and less concentration than this, partly due to high oocyst concentration in clumped solids. It follows that if a faecal release is seen or reported then the pool must be cleared immediately and quickly.

A swimmer swallowing just 10 ml of water would ingest an average of 200 oocysts, which is a dose capable of causing infection (Kebabijan, 1995). The possibility exists that a loose-bowel movement by a child could be greater than 150 ml and also either the same person could have another movement or another swimmer could also have a movement shortly afterwards. Then the average oocyst concentration could exceed 50,000/litre. The UK standard for *C.parvum* oocysts in potable water is a maximum of 1 per 10 litres in a sample of 1000 litres collected over 23 hours, without differentiating between viable and non-viable oocysts. This bears no relevance to what might be an infective dose. This is because infectivity depends on the resistance by the individual ingesting viable oocysts and upon the source and strain of the oocysts. Some individuals might succumb to just one oocyst. In potable water treatment in the UK this standard is achieved mainly through a combination of optimal coagulation, clarification and filtration. Inactivation is not yet accepted in the UK as an alternative to removal partly because of doubts concerning effectiveness of inactivation methods in full-scale application.

Removal & Inactivation

If the potable water standard (1 oocyst per 10 litres) were to be applied to pool water, then a contamination level of 50,000 /litre would require more than 5x105 removal, i.e. 6-log removal. Therefore, there is need for pool filtration systems to be capable of removing this level of contamination in an acceptable period of time. The overall strategy in potable water treatment for microbiological quality control is one of using multiple barriers and in principle this applies to swimming pool water treatment with the combination of filtration and disinfection. In applying the potable water standard for *C.parvum* oocysts, it follows that filtration for removal of oocysts takes priority over treatments to inactivate oocysts. However this does not mean that treatments to inactivate oocysts is much less important, because of its contribution to reducing infectivity of oocysts in pool water or captured within filters and not yet discharged from the system by backwashing of the filters.

It follows that treatments that inactivate oocysts should do so in a much shorter time than it takes for filtration to remove them. Since there is the risk that oocysts within clumps might be protected from inactivation, a robust treatment strategy must be one with a combination of both an acceptable rate of removal and rapid inactivation. A maximum acceptable time might be the period for which a well-used pool is closed overnight (with treatment continuing) say, from 10 pm to 6 am, i.e. 8 hours.

C.parvum oocysts are removed by filtration, but effectiveness of removal depends on the efficiency of filtration, which in turn depends on size of filter media and depth, filter bed condition, filtration rate and the use of coagulation and its optimisation. *C.parvum* oocysts are extremely resistant to normal pool water disinfection practices with chlorine: a reason why pool operators must endeavour to maximise the effectiveness of their filters. Inactivation of oocysts is greater when ozone, chlorine dioxide or UV irradiation are also used. However, the effectiveness of these depends on time and exposure of the oocysts to them. Many pools have ozone installations. A stabilised liquid form of chlorine dioxide (understood to be a tetra-chloro deca-oxide complex (TCDO) - known as Hydroxan(r) and is approved in the UK for pool water treatment) is available and used in the UK. UV irradiation is used at a small number of pools. Synergism in inactivation of oocysts occurs when two methods of disinfection are used sequentially. Thus chlorination becomes more effective when used in combination with ozone or chlorine dioxide. Oocysts could also become "stressed", such as by passing through filters and therefore be more readily chemically inactivated.

In order that pool operators might operate their pool water treatment to best effect to inactivate and remove *C.parvum* oocysts they need to understand what the options are available to them, and to understand the chemistry and process engineering of these. A starting point is "Swimming Pool Water Treatment & Quality Standards" published by the Pool Water Treatment Advisory Group (PWTAG, 1999). Attention is also drawn to the advice by Kebabjian (1995) and to the PWTAG guidelines concerning pool operations when contamination of pool water by *C.parvum* is suspected (PWTAG, 2001). Pool designers and operators will also find the "Guidance Manual Supporting Water Treatment Recommendations from the Badenoch Group of Experts on Cryptosporidium" (UKWIR, 1998) and the 1999 UKWIR report (1999) useful.

So far there is negligible information available on the inactivation and removal of *C.parvum* oocysts by pool water treatments since so few investigations involving pool water conditions have been carried out and results published. However, the potable water industry, especially in the USA and the UK, has been investigating *C.parvum* inactivation and removal for more than a decade. As a result, much has been published in recent years. Although there is much in the literature to learn from there are a number of issues to accepting the viability of the research to real application. Firstly, most of the research has involved small-scale laboratory bench studies. Secondly, the studies have used cultured *C.parvum* oocysts and the robustness of the oocysts can vary substantially between sources and batches. It is believed that there is also considerable variation in robustness of oocysts arising in the wild and therefore also arising from release by humans. Thirdly, different methods are also used by researchers for assessing whether oocysts are viable and for determining the concentration of viable cells. However, standardisation in procedures is taking place. These issues are reviewed in the Badenoch (HMSO, 1990, 1995) and the Bouchier reports (HMSO, 1998). There is also a fourth issue being the difference between potable and pool water treatments, potable water treatment involves single pass and pool water treatment involves almost total recycling of water.

Although the information available can not provide confidence as to how effectively existing or proposed pool water treatments can inactivate and remove *C.parvum* oocysts, the information does provide a basis for estimating how well treatments might work and therefore can also be a basis for benchmarking treatments at pools.

Removal

Filtration

In potable water treatment, filtration is regarded important in disinfection as a physical barrier. This philosophy also applies to pool water treatment. It is clearly established in potable water filtration that the efficiency of filtration for removal of particulates (colloids and microorganisms) is dependent on the optimisation of coagulation. In potable water treatment coagulation is widely used with optimisation of coagulant dose. When an aluminium coagulant is used, optimisation of pH is also necessary (Gregory & Miller, 1994; Gregory et al, 1996; Hall, 1997; AWWA, 1999) and for pool waters should be less than pH 7.5 in order to minimise aluminium solubility. Polyaluminium chloride (PACl) can work better than aluminium sulphate (alum) and at a slightly higher pH. However, there are many pools where coagulation is never or rarely used, used intermittently or only briefly after filter backwash. The lesson from potable water treatment is that coagulation, optimised for coagulant dose and pH, should be used continuously. It is important to note that, in addition to having continuous and optimal coagulation, good filter performance is also dependent on having filter beds in good condition maintained by effective backwashing with the wash water rate appropriate for the water temperature.

Huck et al (2001) have carried out an extensive study of *C.parvum* oocyst removal by filtration. Their studies included comparison of filtration without coagulation, with sub-optimal coagulation and with optimal coagulation. Their results from pilot plants at two sites using formalin-inactivated oocysts showed the substantial importance of optimal coagulation. At both sites there was a 2-log (i.e. 102) difference in oocyst removal between optimal and suboptimal coagulation. However, whilst at one site with optimal coagulation average oocyst removal was about 3-log, at the other site it was about 5.5-log. This level of removal with optimal coagulation has also been found by others, such as by Hall et al (1994). Huck et al also found with optimal coagulation at both sites, that as the need to backwash approached removals were similar, having declined to about 2-log. Also at both sites oocyst removal without coagulation was only about 0.2-log.

It is unclear how oocyst removal might be affected by filtration rate and this is important since pool filters are used not only at rates similar to those used in potable water treatment, about 10 m/h, but also at rates greater than 25 m/h. Filtration at 25 m/h can not be expected to be as effective at removing oocysts as filtration at 10 m/h. McNaughton (1979) examined the effect of filtration rate (11.5, 23 and 37 m/h) in pool water treatment and reported that the effect of filtration rate on filtered water turbidity (a measurement of particulate contamination) was not substantial up to a rate of about 23 m/h. However, examination of his results indicates that filtered water turbidity approximately doubled for a 2-fold increase in filtration rate. This is reflected in some particle count results reported by Yates et al (1997) who examined filtration rates of 7.4, 14.7 and 22 m/h. Particle removal is affected by both filtration rate and influent solids concentration i.e. the solids loading rate. Increase in solids loading rate, due to increase in either or both filtration rate and solids concentration, reduces filter run length to breakthrough. Increase in solids loading rate also results in poorer base line and run-average filtered water quality. It follows that oocyst removal also should depend on filtration rate. Pilot plant results produced by Walker et al (1992) showed that with aluminium coagulation, breakthrough of aluminium increased approximately in direct proportion to increase in solids loading rate. When optimal coagulation is carried out, it is reasonable to assume that the coagulant metal ion concentration is an acceptable surrogate for the concentrations of all other particulate matter including oocysts. Consequently, it can be assumed (probably conservatively) that a 2-fold increase in filtration rate halves oocyst removal.

It follows that pool filters operated with efficient coagulation, with pH less than 7.5, filter beds with 16:30 BS mesh sand with depth of about 0.7m and at low filtration rates (about 10 m/h) could be rated with reasonable confidence for about 3-log removal of oocysts. As filtration rates increase the log-removal rating must be expected to decline. It is suggested that, as above and in the absence of more suitable supporting evidence, the log-removal rating for filtration follows the halving rule as in Table 1.

Table 1: Suggested *C.parvum* log-removal ratings for pool filters

Filtration rate m/h	10-14	15-19	20-24	25-29	30-34	35-39	40 -
Removal – $\log_{10}(N/N_0)$							
good coagulation	3	2.2	1.8	1.5	1.25	1.1	0.95
poor coagulation	1	0.75	0.6	0.5	0.4	0.35	0.3
no coagulation	0.25	0.19	0.15	0.12	0.10	0.09	0.08

GAC Filtration

When ozonation is also used then this must be followed by filtration through granular activated carbon (GAC). The filtration rate through GAC filters is usually high, typically 25 to 30 m/h. The grain size of the GAC is usually a size larger than the sand used in the filtration prior to ozonation. Therefore, the GAC filters can not be expected to be as efficient as the sand filters. However, ozonation can enhance the filtration of particles of similar size to *C.parvum* oocysts (Hall et al, 2001). Consequently, GAC filters may well provide some useful oocyst removal rating. However, information is not known to be available on which to base an estimate of removal rating. In the absence of such information, for a probably conservative estimate the removal rating is condidered to be one third that suggested in Table 1 for sand filters.

Shearing Stress

Ballantyne et al, (1999) evaluated the use of microbial indicators for Giardia and Cryptosporidium inactivation when disinfecting with chlorine dioxide They found the impact of filtration "stress" appeared to weaken Bacillus subtilis spores and render them 1.7 times more susceptible to chlorine dioxide inactivation when compared to "non-stressed" spores during bench-scale experiments at 20°C. It is assumed that shear stress resulting from contact with granular filter media damaged the spore coat and consequently facilitates easier access of chlorine dioxide into the cell thereby enhancing inactivation. Thus, to achieve a desired microbial inactivation level, less chlorine dioxide may be required to inactivate "stressed" spores when compared to "non-stressed" spores. Since published Ct values have been developed using non-stressed Giardia cysts and Cryptosporidium oocysts, treatment facilities with filtration may actually achieve higher microbial inactivation levels than those predicted. However, Chauret et al (1996) tested *C.parvum* oocysts stressed by a number of environmental factors and found their susceptibility to chlorine or chloramine was not changed. Consequently, if physical stressing (as distinct from synergism in chemical inactivation) does occur it can only be regarded as a bonus.

Inactivation

Chlorine

Chlorine, as gas or as sodium or calcium hypochlorite, is the disinfectant most widely used for public and other large pools. The effectiveness of chlorine as a disinfectant is a function of its residual concentration, C, and time of contact, t minutes, in terms of the Ct value. For a pool, the Ct value is most simply determined as the chlorine concentration in the water as measured prior to filtration and the theoretical pool turnover period (total pool, balance tank, pipework and filter volume divided by the pumping rate). More correctly, the Ct value should be calculated to take account of decay in chlorine concentration as the water passes through the system and the hydraulics of the system (i.e. to what extent the retention characteristics of the system reflect plug and totally mixed flow conditions). In practice there is a practical limit to the sophistication of the calculation. Results of bacterial, and other organisms, inactivation by chlorine and other disinfectants are usually shown graphically as log-reduction in organism concentration for increase in Ct value. This is the approach taken also for results of most investigations of the inactivation of *C.parvum* oocysts.

Various investigators have shown that *C.parvum* oocysts are extremely resistant to chlorine. Very large Ct values are needed for chlorine to achieve distinct inactivation. Driedger, Rennecker & Marinas (1999) found that for inactivation of *C.parvum* with free chlorine the inactivation rate decreased as pH increased, consistent with hypochlorous acid, not the hypochlorite ion, being primarily responsible for *C.parvum* inactivation in the pH range of 6.0-8.5. Korrich et al (1990) reported mouse infectivity became zero for doses of 600, 6000 and 6x104 oocysts, at 25°C and pH 7, for Ct values of 4800, 7200 and 9600 respectively. Carpenter et al (1999) reported that mouse infectivity to a dose of 150,000 oocysts becomes zero for *C.parvum* oocysts treated with hypochlorite at 30°C, pH between 7.2 and 7.8, with a Ct value of 2880 mg.min/l. Thus, confident 5-log inactivation by chlorine in pool water would appear to require Ct values of at least about 3000 and possibly more than 10,000. This means that for pool water with a chlorine residual of 0.8 mgCl/l a minimum contact time of 3,600 minutes (60 hours) is required to produce between 3 and 5-log inactivation. The results by Korrich et al cannot be used to predict inactivation at low Ct values because they appear to include 0.6-log reduction unaccounted for by Ct. However, both sets of results reflect that Ct values of about 1000 equate to about 1-log inactivation.

For a pool where residual chlorine concentration is, say, 0.8 mgCl/l and the turnover time is two and a half hours (i.e. 150 minutes) then the nominal Ct value is 120 mgCl.min/l. This will provide negligible effective log-inactivation of oocysts (possibly in the order of 0.1-log). However, if the pool is closed for 8 hours overnight and the water continues to be recirculated but with a chlorine residual of 1.5 mgCl/l, then the Ct value for this will be 720 mgCl.min/l. This value, for a water temperature of about 30°C, would be expected to produce measurable, albeit still small, oocyst inactivation providing pH is low enough. It is partly for this

reason why, when a faecal release incident in a pool occurs, pool operators are advised to close the pool and maintain circulation and chlorination.

It is because chlorination appears to be so inadequate for *C.parvum* inactivation that so much attention is being given to using other disinfection strategies, not withstanding the role of filtration in oocyst removal.

Ozone

Investigators have shown (Driedger et al, 1999; 2000) that ozone is a far more effective for inactivation of *C.parvum* oocysts than chlorine. They have also shown (Driedger et al, 2000; Rennecker et al, 2000) that there is even greater inactivation (i.e. synergism) when ozone is used in the presence of chlorine. Table 2 gives the log-inactivation by ozone alone proposed by Rennecker et al (2000).

Table 2: Proposed minimum Ct values for inactivation of *C.parvum* oocysts with ozone at 30°C (27)

Inactivation – $\log_{10}(N/N_0)$	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Ct mg.min/l	0.62	1.01	1.40	1.79	2.18	2.57	2.96	3.35	3.74	4.13	4.52	4.91

It has been usual for ozonation in pool water treatment to apply doses that result in small residuals after 3 to 5 minutes. This is because the ozone is applied to little more than satisfy, what might be termed (Roustan et al, 1998; Park et al, 2001), the instantaneous ozone demand and to maximise the life of the carbon in the subsequent carbon filter needed to prevent ozone in water passing into the pool because of its toxicity and potential detrimental impact on building structures. Most ozone installations in the UK probably follow the BEWA "Code of Practice for Ozone Plant in Swimming Pool Water Treatment" (BEWA, 1990). This says that a minimum concentration of 0.4 mgO3/l after a contact time of not less than 2 minutes should be the design criterion. This equates to a Ct value of 0.8 mg/l-min, and at 30°C might be equated with a potential *C.parvum* oocyst 0.8-log inactivation, not allowing for inefficiencies. To achieve 6-log inactivation the pool water would need to be subjected to 7.5 turnovers, which may be viewed as unacceptably long. To achieve 6-log inactivation within 8 hours for a pool with, for example, a 3 hr turnover, the Ct value would need to be at least 1.84. This could be achieved by either or both increasing the ozone dose and contact time. The space in existing pool plant rooms would make it very difficult to provide additional contact time. Increasing ozone dose so that there might be a larger residual would reduce carbon life. From a safety perspective, it would also be important to ensure carbon filter contact time is long enough to remove all residual ozone.

Synergy was observed in the sequential inactivation of *C.parvum* with ozone and free chlorine (Driedger et al, 2000; Rennecker et al, 2000). Secondary inactivation curves were characterised by relatively rapid initial decline in viability followed by slower inactivation kinetics. Greater synergy was observed at pH 6 than at pH 7.5 and no synergy was observed at pH 8.5 (Rennecker et al, 2000). Additionally the rate of secondary inactivation with free chlorine decreased with increasing pH, again consistent with hypochlorous acid being the free chlorine species primarily responsible for *C.parvum* inactivation in the pH range 6.0-8.5.

Chlorine Dioxide

Chlorine dioxide is not as effective as ozone in inactivating *C.parvum* oocysts. For similar Ct value, the effectiveness of chlorine dioxide at 30°C is about as effective as ozone at 5°C. Chlorine dioxide has to be generated on-site unless stabilised forms are used. The draw-back with using chlorine dioxide for all but one known method of sourcing it is that the by-products chlorite and chlorate will exceed approved maximum concentrations in pools. The known exception is the proprietary product Hydroxan(r), which has to be used in combination with chlorine to be effective. The Queensland (Australia) Code of Practice (1998) advises that stabilised chlorine dioxide (liquid) and not on-site generated gas be used. It suggests that a Ct value of 78 results in inactivation greater than 90 percent at normal pool temperatures and pH. It also suggests a dose of 0.25 mg/l for 6 hours to achieve this.

Table 3 gives the proposed minimum Ct values for inactivation at 30°C as determined by Ruffell, Rennecker & Marinas (32). The Ct values in the table

mean that for a chlorine dioxide concentration of 0.3 mg/l a 6-log inactivation is predicted for a contact time of 340 minutes, i.e. almost 6 hours. Alternatively, 6-log inactivation would be achieved in 8 hours for a chlorine dioxide residual of 0.21 mg/l. It is assumed that whilst these results were produced using gaseously produced chlorine dioxide, they also apply to chlorine dioxide sourced from stabilised forms.

Table 3: Minimum Ct values for inactivation of *C.parvum* oocysts with chlorine dioxide at 30°C proposed by Ruffell, Rennecker & Marinas (32)

Inactivation – $\log_{10}(N/N_0)$	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Ct mg.min/l	14.1	22.1	30.2	38.2	46.2	54.2	62.2	70.3	78.3	86.3	94.3	102

Corona-Vasquez, Rennecker & Marinas (1999) found that Ct values of 1,600 and 5,200 mg.min/l for chlorine are required to decrease viability by 1-log at 20 and 4°C respectively, after 1-log inactivation with chlorine dioxide at pH 6. It follows that synergism will be less for a pool water pH of 7.2-7.5 but greater for a temperature of 30°C. Therefore, one might expect for normal pool water temperature and pH that synergism might account for 1-log inactivation for a Ct value of about 1600. Consequently, a chlorine residual of 1.0 mgCl/l for 8 hours, having a Ct value of 480, might have a synergistic value of about 0.25-log inactivation.

UV Irradiation

Investigations have shown (Bukhari et al, 1999; Craik et al, 2000; Clancy et al, 2001) that UV irradiation appears to be particularly effective in *C.parvum* oocyst inactivation. However, the drawback is that UV irradiation results in enhancement of trihalomethane (THM) concentrations (Judd et al, 1998; Bronda). To avoid this it needs to be used in conjunction with ozonation and GAC filtration that is adequate to minimise THM enhancement. The effectiveness claimed for UV, based on model waters in simple bench tests, would appear to be remarkable. However, confidence with application to pool treatment might be best deferred until there is more evidence of the effectiveness of UV to inactivate oocysts when applied to real pool waters in continuous flow conditions.

Application

Benchmarking

Benchmarking of a treatment system (i.e. the pool water treatment plant) is assessment of the systems performance, and its individual unit processes (e.g. filtration, chlorination, pool retention time) with comparison to a reference or set of references. The references may be the performance of other plants or the performance of the system predicted from modelling the system. However, actual evaluation of pool water treatment plants for their inactivation and removal of *C.parvum* oocysts would be very expensive, and difficult, to carry out. Therefore, benchmarking based on prediction of performance is the more attractive option.

Only recently has enough information been published, albeit with respect to potable water treatment as referenced, that allows prediction of the possible efficiency of pool water treatment strategies for *C.parvum* oocyst removal and inactivation. Although the viability of this information is limited by the issues mentioned, it does provide a basis for evaluating existing and proposed pool water treatment strategies. The information is already being used in this way for potable water treatment.

Example 1

Consider a pool where treatment consists of filtration at a rate of 30 m/h applying coagulation only for a couple of hours after backwash, a pool turnover period of 2.5 hours, average chlorine residual of 1.5 mg/l at pH 7.5 and no other treatments. In eight hours the pool would have 3.2 turnovers. The removal rating for the filtration would be assessed as having no coagulation and therefore in 8 hours would only achieve, with reference to Table 1, a total rating of (0.10 x 3.2 =) 0.32-log. The chlorination for 8 hours has a Ct value of (1.5 x 8 x 60 =) 720 and this relates to an inactivation rating of about 0.7-log. For this example, probably representative of many pools in the UK and elsewhere, both the removal and inactivation ratings are very low and effectively worthless for controlling *C.parvum* oocyst contamination. Substantial increase in the level of removal could be achieved by introducing continuous and optimal coagulation.

Example 2

Consider a pool with a filtration rate of 25 m/h with continuous but not optimal coagulation, pool turnover of 2.5 hours, ozone dosed for a residual of 0.4 mg/l for a contact time of 2 minutes, GAC filtration rate also 25 m/h and a chlorine residual of 1.5 mg/l. The removal rating for a period of 8 hours for the sand filters would be (0.5 x 3.2 =) 1.6-log and for the GAC filters would be 0.5-log, being a total of 2.1-log. The ozonation has a Ct value over 8 hours of (0.4 x 2 x 3.2 =) 2.56, which equates to an inactivation rating, with reference to Table 2, of 3-log. The chlorination, as for Example 1, has a rating for itself of 0.7-log. The chlorine following ozonation will also have an inactivation rating due to synergism of about 0.7-log. Therefore the combined 8-hour rating for inactivation is about 4.2-log. For this example the removal and inactivation ratings are substantially greater than for Example 1 but still short of the target of 6-log. The removal rating could be improved by applying optimal coagulation.

Example 3

Consider a pool with a filtration rate of 20 m/h with continuous and optimal coagulation, a pool turnover of 2.5 hours, chlorine dioxide (i.e. TCDO-complex) dosed for a residual of 0.25 mg/l in conjunction with a chlorine residual of 1.0 mg/l. The removal rating for a period of 8 hours by the filtration would be (1.8 x 3.2 =) 5.76-log. The chlorine dioxide has a Ct value of (0.25 x 8 x 60 =) 120, which equates to an inactivation rating, with reference to Table 3, greater than 6-log. To this can be added the small inactivation rating of about 0.5-log due to chlorine alone and its synergistic contribution. For this example, the removal rating almost meets the target and the inactivation rating exceeds the target.

Discussion

The above draws upon information that is now available in the literature and enables an assessment to be made of the potential ability of pools and their treatment systems to cope with a release of *C.parvum* oocysts by removal and inactivation. Information is not known to be available on inactivation by any other disinfectants used in pool water treatment other than those mentioned. The information, albeit mostly produced in the context of potable water, would suggest that a large proportion of pools, as reflected by the examples, have treatment regimes that are inadequately effective for removing and inactivating *C.parvum* oocysts in a practical timescale. Pools with a low removal rating need to apply a combination of better coagulation, slower filtration rate and faster pool turnover. Pools with only chlorination need to improve their inactivation rating by applying an additional method of disinfection.

It is important to note that Ct values and log-ratings in the above tables apply to a water temperature of 30°C. For lower temperatures, Ct values will need to be greater for the same log-reductions or log-reduction will be less for the same Ct values. It is also important that assessment of treatment strategies should take account of disinfection by-product control and other quality control criteria.

There is a substantial need for investigations to be carried out to demonstrate the extent to which the information available does apply to pool water treatment and can be used to predict removal and inactivation by pool water treatments with confidence. In the meantime, the information available provides something that can be used. However, it is important to note that the information provides only an assessment of potential ability or a basis for comparative ability. It is also important to note, until proven otherwise, the information is not a basis for providing a confident prediction or guarantee of the performance of treatments to control *C.parvum* oocyst contamination. Further, even with a high removal and inactivation rating, action by pool operators following a known faecal release should follow the published guidelines of clearing the pool of bathers and disinfecting and filtering - with effective coagulation - for a minimum period. However, the minimum period might take account of the removal and inactivation rating.

Conclusions

1. Information is now available in the literature that enables an assessment to be made of the potential ability of pools and their treatment systems to remove and inactivate *C.parvum* oocysts.

2. The information, albeit mostly produced in the context of potable water, would suggest that a large proportion of pools have treatment regimes that are not effective for removing and inactivating *C.parvum* oocysts in a practical timescale.

3. There is a substantial need for investigations to be carried out to demonstrate the extent to which the information available applies to pool water treatment and can be used to predict removal and inactivation by pool water treatments with confidence.

4. Regardless of whether a pool can apply adequate treatment (removal and inactivation), the action following a known faecal release by a bather should follow the published guidelines of clearing the pool of bathers and applying disinfection and filtration (with effective coagulation) for a minimum period (reflecting the efficacy of the treatments applied).

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