Decontaminating and managing cry

The management of Cryptosporidium affects all pool operators, and there is a need for the optimisation of treatment of all swimming pools

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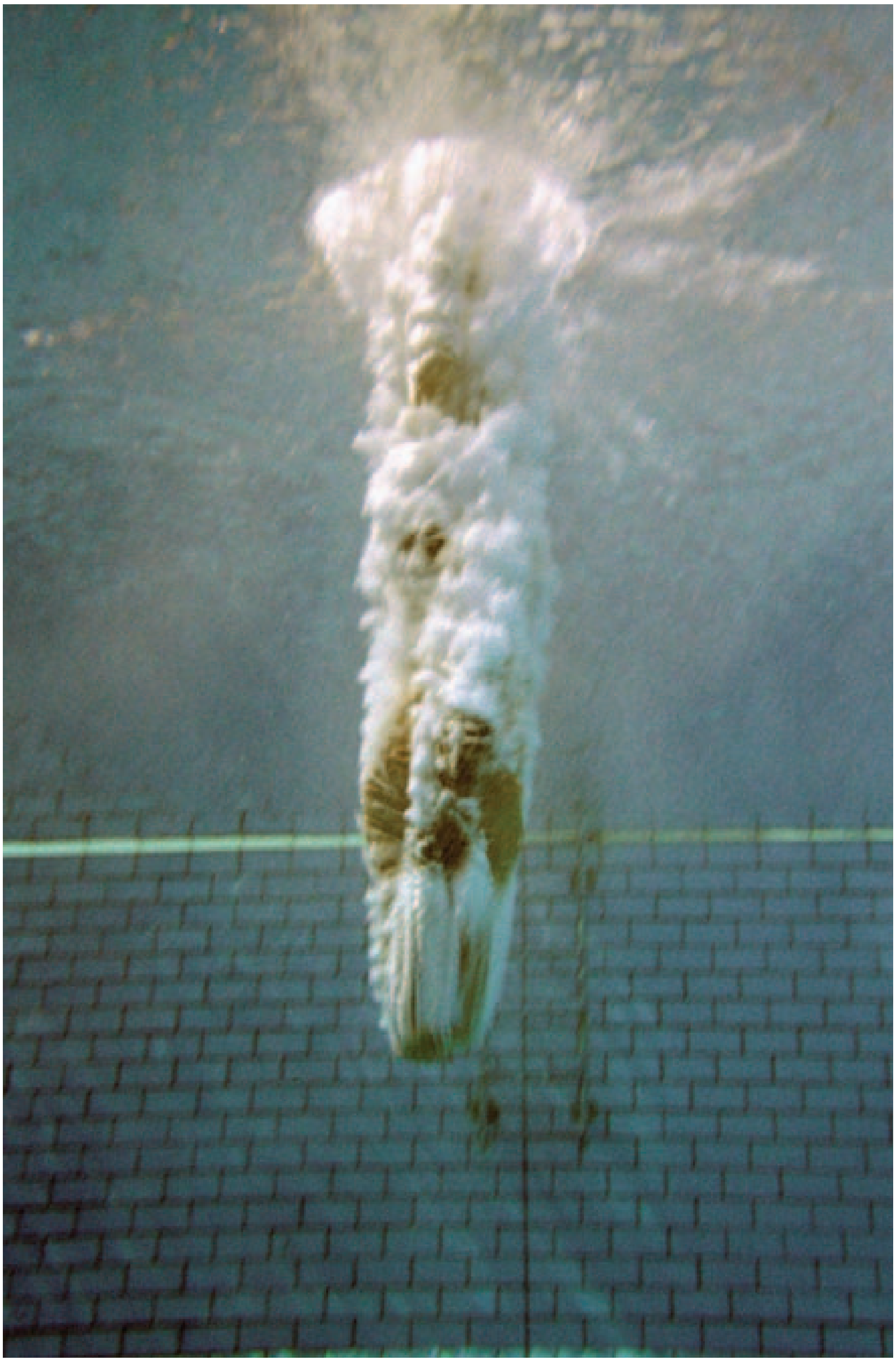

There is still virtually no experimental or field information on the removal of Cryptosporidium oocysts, or their inactivation during filtration and disinfection under pool water treatment conditions. The new data, from work on filtration of oocysts during drinking water treatment, are reviewed and shown to confirm previous conclusions that continuous dosing of a coagulant under optimal conditions is needed to achieve efficient oocyst removal. Work on drinking-water disinfection has shown that, under the appropriate conditions, disinfectants can give high inactivation of oocysts as judged by the mouse infectivity assay. However, doubts remain as to the suitability of mouse infectivity assay as a model of human infectivity. Simple modelling of pool flows has confirmed the PWTAG recommendations for treatment and pool turnovers, following a Cryptosporidium contamination.

Introduction

PHLS has recorded a number of Cryptosporidium outbreaks, which were concluded to have originated from swimming pools. In most cases, direct faecal contamination of the pool was suspected or known to have occurred. As a result of these incidents, the Pool Water Treatment Advisory Group (PWTAG) has issued guidance on the course of action to be taken in the event of faecal contamination of a pool (Pool Water Treatment Advisory Group 1999).

There is virtually no experimental or field information available on the removal of Cryptosporidium oocysts by pool filtration and

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disinfection (Pool Water Treatment Advisory Group 2000). A lot of information is available for drinking water treatment, but generally the conditions are different. Drinking water treatment is a once-through and not a recirculating system, as is pool treatment. Drinking water chlorination levels are lower, filtration rates slower and the temperature lower and more variable. Nevertheless, it is possible to predict the likely effectiveness of pool water treatment for Cryptosporidium removal, as was used by PWTAG in drawing up its guidance. The information available has been reviewed and the procedures for dealing with Cryptosporidium endorsed. (Croll Brian 2000, The Institute of Sport and Recreational Management 2000)

The more recent drinking water research into high-rate direct filtration (i.e. no settlement or flotation stage of solids removal prior to filtration) and further developments in disinfection, are reviewed in the light of pool water treatment.

Simple mathematical modelling of pool flow characteristics has confirmed the PWTAG recommendations, with respect to the number of pool turnovers required before returning a pool to operation after a contamination incident, and indicated the necessary Cryptosporidium removal efficiency required to make the recommendations effective.

Drinking water filtration

Work on drinking water filtration, at the normal drinking water filtration rates of 5 to 10 m/hr, has confirmed the previous conclusions that, without a coagulant, Cryptosporidium oocyst removal is less than 90 per cent. With optimal coagulation and flocculation, using a coagulant such as aluminium sulphate, removals can be as high as 99.9 to 99.99 per cent (Croll 2000).

Rapid filtration at similar rates to those used in pool filtration (12 to 40 m/h) are generally performed using coarse media (1 to 2 mm particle size) and deep beds (1.5 to 2.5 m) in drinking water treatment. Such filters have the advantage of high rates and long filter runs, provided that the turbidity is below 20 FTU. As with lower rate filtration, oocyst removal has been confirmed at up to 99.99 per cent dependant on the optimisation of coagulation and flocculation, one paper quoting a drop from 99.5 per cent to 95 per cent removal when sub-optimal coagulation and flocculation was in use (Croll 2000). At Ottawa, removal was investigated with no coagulant and almost no removal of oocysts was observed (Emelko M B, 2001; Huck P M, Coffey B M, O'Melia C R and Emelko M B, 2000).

Disinfection

When a disinfectant attacks a Cryptosporidium oocyst, it penetrates the oocyst wall to inactivate the sporozoites inside. Normally the oocyst appears unaltered. The effectiveness of disinfection, therefore, depends on being able to assess whether the sporozoites are alive or dead.

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The tests used are called viability or infectivity tests and can be dye staining methods, as favoured in the UK, or by testing in mice (mouse infectivity tests) as favoured in the USA and Canada. The two systems give very different answers and the mouse infectivity tests normally show a much greater degree of inactivation of oocysts by disinfection. New tests based on human cell cultures, give results that are very similar to the mouse infectivity testing. How well the tests indicate infectivity in humans is still a matter of debate. To date, disinfection alone has not been advocated in the UK for swimming pool decontamination, due to the possibility of shielding of the oocysts by faecal matter, the debate on viability tests and the variability of the published data on the ct (disinfectant concentration in mg/l x time of application in min) required.

The results based on mouse infectivity testing are summarised below.

Chlorine

Free and combined chlorine continue to be shown to be ineffective at doses possible in either drinking water or normal pool water treatment (ct >8000mg/l/min at 22OC for 99 per cent inactivation, (Oppenheimer J and others 1998, Gregory 2002). However, it has been suggested in the USA (Greenberg G, 2001), that in the event of a liquid stool contamination, and consequent pool closure, an effective ct value at 30OC could be achieved by raising the free chlorine to 20 mg/l at pH 7.2 to 7.5 for at least 8 hrs (ct at least 9600mg/l/min). The advice also emphasises the need to maintain circulation and filtration in order to minimise the possibility of particulate matter shielding the oocysts from the disinfectant.

Chlorine Dioxide

Chlorine dioxide is much more effective than chlorine (ct 38.2 mg/l/min at 30 OC for 99 per cent inactivation, Ruffel K M, Rennecker J L and Marinas B J 2000) but it normally degrades to chlorite and chlorate. Under Regulation 25 of the UK Drinking Water Regulations the sum of chlorine dioxide, chlorite and chlorate is limited to 0.5 mg/l. This effectively limits the total chlorine dioxide dose to 0.5 mg/l and it is of little practical value for Cryptosporidium control in drinking water in the UK, as the necessary residuals can rarely be maintained for long enough. Although the necessary contact times are available in pools, a build-up of chlorite and chlorate in pool water is also undesirable, restricting the use of chlorine dioxide for Cryptosporidium control when generated from chlorite and free chlorine or hydrochloric acid. The use of a 'stabilised chlorine dioxide' compound (Rimpler M, Regnet Wand Pacik D 1992) and free chlorine can avoid a build-up of chlorite and chlorate and, assuming that this method of generation has the same effect on Cryptosporidium, the theoretical ct values can be achieved at realistic doses (Gregory R 2002).

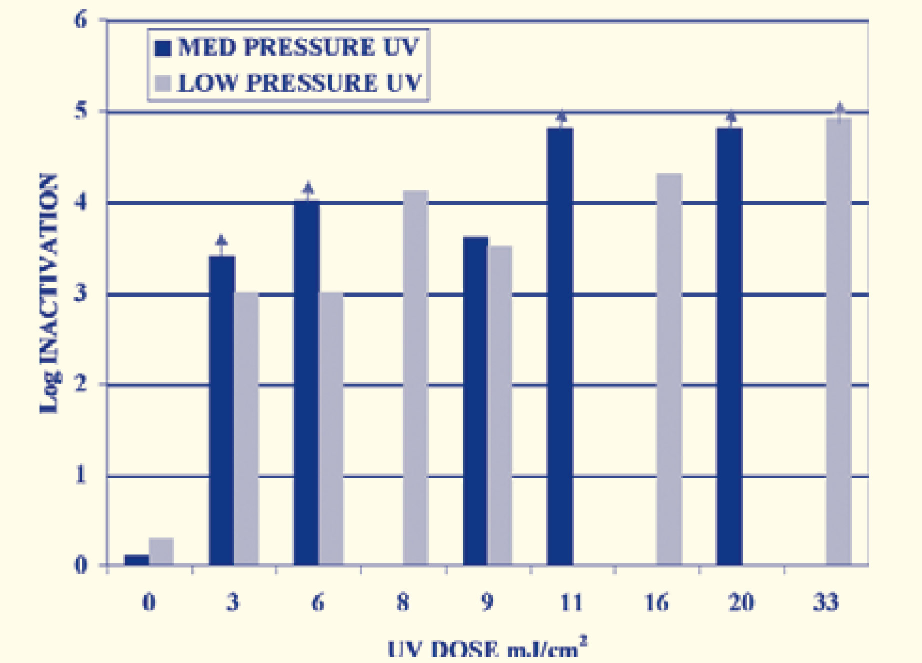

Figure 1. Mouse Infectivity Inactivation of Cryptosporidium by UV.

Ozone

Ozone has been confirmed as effective for Cryptosporidium inactivation. Applied at drinking water disinfection doses (0.3 mg/l after 10 to 20 min contact, ct 3 to 6 mg/l/min) at 30OC it would give better than 99.9 per cent kill of oocysts as estimated by mouse infectivity (Rennecker *et al* 2000). However, at swimming pool doses (0.4 mg/l after 2 min contact, ct 0.8) the kill would be below 90 per cent.

Ultra Violet Irradiation

Studies into ultra violet irradiation have confirmed the earlier results that it is highly effective. It is now thought that both low- and medium-pressure UV lamps give excellent results as shown in Figure 1 (Clancy *et al* 2001). A normal UV dose for pool treatment is 60 mJ/cm2, almost twice the highest dose shown in figure 1. However it is often used as a side stream process, and mixing and dilution would then need to be taken into account. (1 log removal is 90 per cent, 2 log 99 per cent, etc)

Pool turnovers after a liquid faecal incident

The flow characteristics of a pool, or any other water storage vessel, will have considerable influence on the number of pool turnovers required to clear a contamination down to acceptable levels. Basically, two types of flow exist:

- Plug Flow, where the contamination would move as a discreet volume of contaminated water through the pool, with little mixing with adjacent water; or
- Fully mixed, where the contamination would mix rapidly with the whole volume of water in the pool.

In most cases, the real situation will be a mixture of the two basic flow patterns and may be complicated by factors such as learner pools feeding to the main pool treatment plant. The calculations in this section are simplistic; initial calculations of the influence of the two basic flow patterns, with the number of pool turnovers required to reduce a liquid faecal contamination to acceptable levels. The implications of this on pool water treatment requirements are discussed.

The incident

It was assumed that a liquid faecal incident had occurred, that 100g of faecal matter were discharged, and that the matter contained 10^6 oocysts per gram (one million per gram) i.e. 10^8 oocysts were discharged. In the case of plug flow, it was assumed that the oocysts were distributed in $1m^3$ of water. In the case of fully mixed flow, the oocysts were assumed to be fully mixed throughout the pool volume in 10 per cent pool turnover time.

Standards to be achieved

It was assumed that the drinking water standard of one oocyst per 10 litres was the standard to be achieved. It may be possible to have a less stringent standard for pool water.

Plug flow

A pool of $1000m^3$ was assumed and the flow was split into intervals of 10 per cent of the turnover time. The plug of contamination was 10^8 oocysts in $1m^3$, i.e. 10^6 oocysts per 10 litres. This will be reduced by a factor dependent on the efficiency of treatment each time that it passes through the treatment system. It was also assumed that when the water was returned to the pool each increment was diluted by a factor of two, due to mixing with the pool water but that this then moved through the pool as plug. A graph showing the results at different removal efficiencies is shown in Figure 2, and an expanded figure of the point at which each line crosses the turnover axis in Figure 3.

It will be seen that, at higher removal efficiencies, less pool turnovers are needed to achieve the required standard, ranging from 10 turnovers at 50 per cent removal to about two at 99.9 per cent removal. Thus, for plug flow, the better the treatment the less pool turnovers are needed to achieve the standard, as would be expected.

Fully mixed flow

The pool size etc. were the same as for plug flow. It was assumed that full mixing was achieved in six minutes and the incremental volumes used

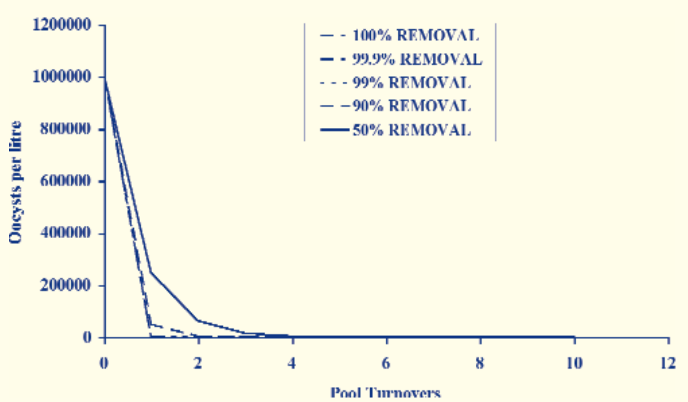

Figure 2 Pool Turnovers - Plug Flow.

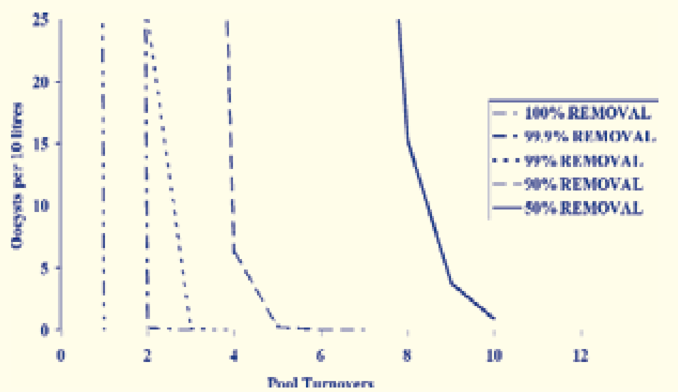

Figure 3 Pool Turnovers - Plug Flow Intercepts.

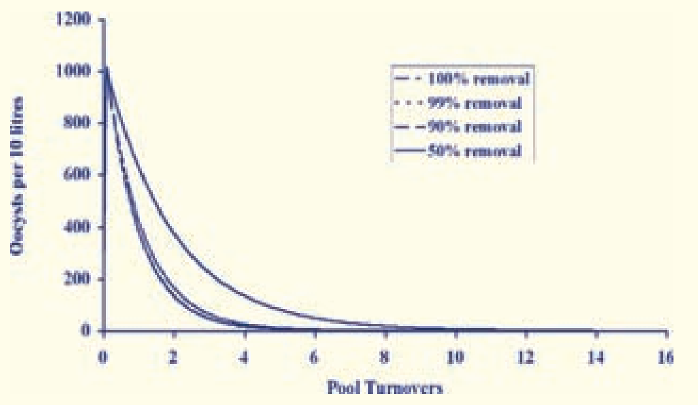

Figure 4 Pool turnovers - Fully Mixed Flow.

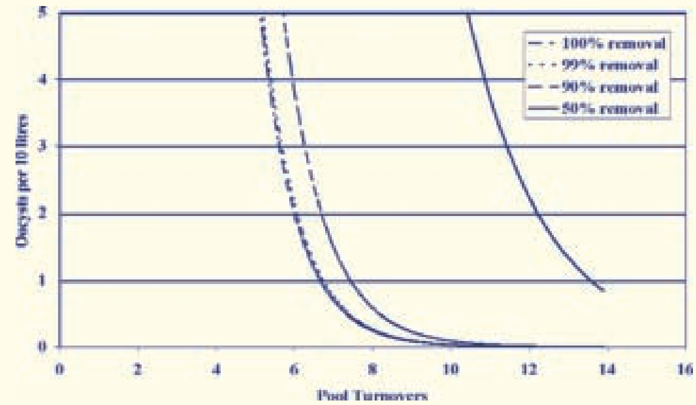

Figure 5 Pool Turnovers - Fully Mixed Flow Intercepts.

were also six minutes. (One-minute incremental volumes were tested and made little difference). Thus, 10 per cent of the pool volume is treated and returned to the pool, where it mixes with the water in the pool, reducing the pool concentration. This process is then repeated. The results are shown in Figure 4 and the intercepts are shown on an expanded scale in Figure 5.

It will be seen, in contrast to the results when assuming plug flow, that although 50 per cent removal gives significantly worse results than 90 per cent-plus, the range of turnovers to achieve the standard at 100 per cent and 90 per cent removal is only 6.8 and 7.6 turnovers respectively. Ninety-nine per cent removal is almost the same as 100 per cent removal.

Thus, if mixed flow is present, then at least six turnovers are required to achieve the standard. As long as the oocyst removal efficiency is better than 90 per cent, then better removal has a relatively small effect and improvements beyond 99 per cent have no effect practically on the number of turnovers needed to achieve the standard.

Discussions and conclusions

There has not yet been any work on the filtration of Cryptosporidium under pool water treatment conditions and pool water quality. PWTAG has initiated research and is currently seeking funding. Recent work on drinking water filtration has confirmed the previous conclusions that up to 99.99 per cent of Cryptosporidium oocysts can be removed when using a coagulant continuously with optimal coagulation and flocculation conditions. When conditions are sub-optimal, this falls to 90 per cent to 99 per cent removal. With no coagulant, removal is negligible to 90 per cent.

The recent drinking water work quoted was mainly performed with deep bed (1.5 to 2.5 metres), coarse media filters at flow rates similar to those used in pool water treatment (15 to 40 m/hr). Translation of this data to pool filtration conditions, where beds of 600mm are operated at high rates, is difficult. Earlier work has shown that optimal coagulation and operating conditions are more important that flow rate (Croll B 2000). It can therefore be concluded that pool filtration will have the whole range of Cryptosporidium removal efficiencies from negligible to 99.99 per cent dependent on the system in use and the efficiency of operation.

'Disinfection alone has not been advocated as a means of Cryptosporidium control in the UK, due to the need to keep turbidity low for effective disinfection'

Simple modelling of pool flow characteristics show a large difference between plug flow and fully mixed flow. For plug flow, the number of pool turnovers needed to clear a Cryptosporidium contamination decreases with the efficiency of treatment at the treatment plant from 1 turnover at 100 per cent removal to just under 5 turnovers at 90 per cent removal. For fully mixed flow, the situation is quite different and, at 100 per cent, removal 6.8 turnovers are needed to clear the simulated contamination. A drop from 100 per cent removal to 90 per cent only requires about one extra pool turnover (7.6 turnovers). As most pools will have mainly mixed flow but an element of plug flow for a contamination, the real situation will lie between the two extremes, given that there are no dead spots. Thus if 90 per cent removal is assumed for a filtration plant with sub-optimal continuous coagulation, then the PWTAG advice of six pool turnovers is confirmed, particularly as a severe contamination was simulated.

The above conclusions confirm the PWTAG advice on Cryptosporidium control, and action to be taken following a liquid faecal incident.

Disinfection alone has not been advocated as a means of Cryptosporidium control in the UK, due to the need to keep turbidity low for effective disinfection, the debate concerning the methods of estimating oocyst infectivity in humans and, for chlorine, the variability of the data on the ct necessary for effective disinfection. However, disinfection could offer additional security in the event of a Cryptosporidium contamination.

This is one of a series of papers presented at the ISRM SportExcel seminar 'Disinfection and Control – the safe management and control of swimming pool water quality.'

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