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Removal of *Cryptosporidium oocysts* by filtration in the treatment of swimming pool waters

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Abstract

In the event of a faecal incident within a swimming pool, once any immediate mitigation measures have been initiated, the removal of any *Cryptosporidium oocysts* that may be present will depend on filtration efficiency. Initial studies using sand media and modified tap water showed that surrogate particles (poly-styrene) could only be removed by around 40% (or less) if no coagulant was dosed prior to the filter, and that with coagulant dosed, removal efficiencies of 90% or better could be achieved. The surrogate particles used were in the range 2 to 7 µm, consistent with the size of oocysts. More recent studies have confirmed these removal efficiencies using real pool water and demonstrated similar removal efficiencies with sand media using live oocysts, with coagulant, at lower concentration loadings. Studies with inactivated oocysts have also indicated better performance with coagulant. Crushed-glass filtration media have also been evaluated using surrogate particles with broadly similar results to sand. Zeta potential studies for a range of pH and salinity conditions have indicated that the characteristics of inactivated oocysts and surrogate particles are similar.

Introduction

The intestinal parasite Cryptosporidium (several species) can cause severe diarrhoea related illness in humans if its infective oocysts are ingested. Whereas the initial concerns related to infection from drinking water, after several well publicised outbreaks of the disease in the UK and US, now that drinking water treatment systems have been improved (or high risk water sources have been abandoned) the focus of concern has shifted to infection from swimming in communal pools. Epidemiological data in the UK (1) indicates around ten outbreaks of cryptosporidiosis occur each year (mostly in the autumn period), linked to communal swimming. In the US (2), a similar pattern has been observed with around five times as many outbreaks, a reflection of the greater US population. In both the UK and US, many of the communal pools do not use coagulant chemicals in their filtration treatment systems. In the event of a faecal incident within a swimming pool, once any immediate mitigation measures have been initiated, the removal of any Cryptosporidium oocysts that may be present will depend on filtration efficiency. It is worth noting that 100g of infected faeces can contain 108 to 109 oocysts (3) and that ingestion of <10 oocysts may cause infection.

This paper provides an update of the filtration research being undertaken by Swansea University in collaboration with the UK's Pool Water Treatment Advisory Group and the Wales National Pool.

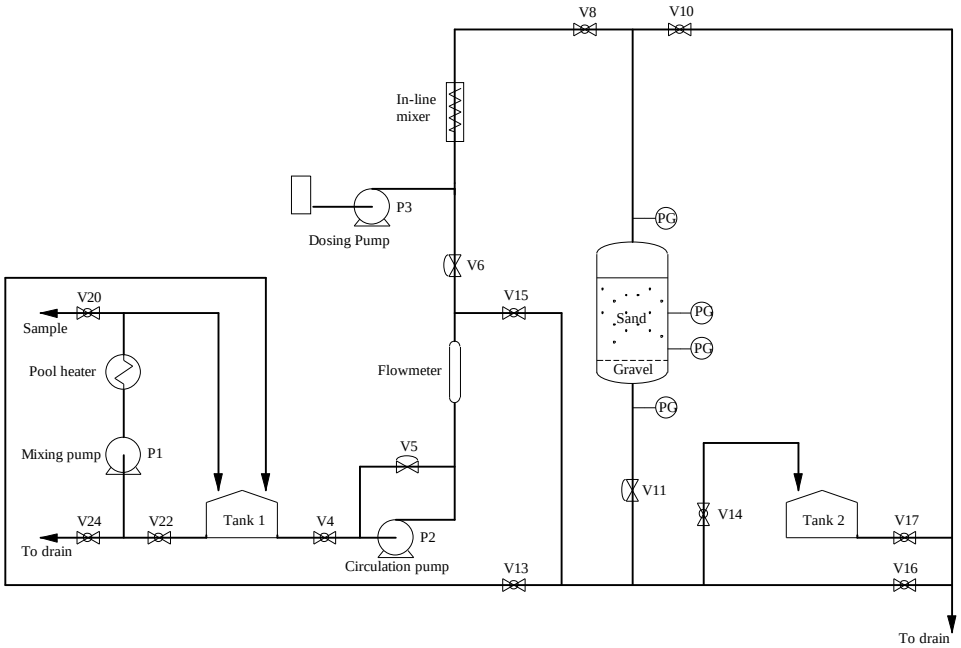
Pilot plant facilities

There are two pilot filtration plants. The first has a 20cm diameter filtration column, with an optional flocculation column, and can operate in either batch or continuous flow-through modes. Initial experimentation was based on modified tap water, whereas more recent work has been based at the Wales National Pool with water feeds being possible from either the 50m competition pool or smaller training pool. The layout of this pilot plant is shown in Figure 1 and Plate 1. The second has a 5cm diameter filtration column and has been engineered with components that can easily be disassembled and auto-claved; it is contained within a microbiological safety cabinet to facilitate experimentation with live oocysts on a batch treatment basis and is shown in Plate 2. Both pilot plants enable chemical coagulants to be dosed prior to filtration.

Plate 1. Large pilot plant at Wales National Pool

Plate 2. Small pilot plant in microbiological safety cabinet

Figure 1. Diagram of large pilot plant layout



Experimental methods

Filtration runs with the larger pilot filtration plant have used surrogate particles. These are made from polystyrene and earlier work (4) confirmed their 2 to 7 µm size range with an average particle size of around 5 µm, similar to the size of oocysts. The surrogate particles are stained with a fluorescent dye to assist enumeration using a microscope. The influent concentration of these particles has routinely been around 104 to 105 per ml as an approximation of a possible "worse-case" condition after a faecal incident. The plant has been operated on a batch treatment basis at a filtration rate of either 25 or 50 m/h. Both sand and crushed glass media (0.5 to 1.0mm media size range) have been evaluated.

Filtration runs with the smaller pilot filtration plant have focused on the same sand media at a filtration rate of 25 m/h, using surrogate particles, live oocysts and inactivated oocysts. To enumerate the surrogate particles, initially water samples were filtered using a membrane and then counted using a fluorescent microscope. In more recent work, membrane filter samples were eluted and counts made using a haemocytometer cell and microscope. To enumerate the oocysts, "Envirocheck" filtered samples were stained with DAPI prior to microscopic counting.

The surface charge characteristics of the surrogate particles and the inactivated oocysts were investigated for a range of ionic strengths and pH conditions; samples were injected into a Malvern Zetasizer 2000 to determine zeta potential, as calculated from electrophoretic mobility.

Filtration results for surrogate particles

The initial sand filtration study in 2004 by Croll et al (5), that used modified tap water and the larger pilot plant, found that surrogate particle removal was less than 50% when no coagulant was dosed, at a filtration rate of 25 m/h and with particle loadings of around 5x104 per ml. With the addition of either PAC or aluminium sulphate at optimal concentrations, removal of particles was more than 99%, and 90% or better particle removal was achieved at minimum coagulant doses of 0.05 mg/l Al for PAC and 0.1 mg/l Al for aluminium sulphate.

In 2007, this pilot plant was moved to the Wales National Pool and sand filtration runs were repeated at 25 m/h using real pool water under both low and high bathing loads, with and without coagulant (PAC). The results are shown in Table 1. It is evident that the percentage removals of the surrogate particles were very similar to those obtained in 2004 and that bathing load was not a particularly significant factor.

Table 1. Sand filtration results using the large pilot plant and real pool water

Run No.	Bather Load	Coagulant Dose PAC mg(Al)/l	pH	Tank 1 particles/ml (filter inlet)	Tank 2 particles/ml (filter outlet)	Mean % Removal
1	Low	0	7.3	8.8E+04	4.1E+04	**54.0**
2	Low	0	7.4	8.4E+04	5.7E+04	**31.9**
3	Low	0	7.4	9.3E+04	5.3E+04	**43.3**
4	High	0	7.4	5.1E+04	3.7E+04	**26.1**
5	High	0	7.6	5.9E+04	4.1E+04	**29.5**
6	High	0	7.5	8.1E+04	5.1E+04	**36.6**
7	Low	0.05	7.4	4.8E+04	5.2E+02	**98.9**
8	Low	0.05	7.4	4.8E+04	1.3E+03	**97.4**
9	Low	0.05	7.5	4.2E+04	9.4E+02	**97.8**
10	High	0.05	7.5	6.7E+04	6.3E+02	**99.1**
11	High	0.05	7.5	6.8E+04	9.0E+02	**98.7**
12	High	0.05	7.5	6.2E+04	3.8E+02	**99.4**

Also in 2007, the small pilot plant was commissioned using modified tap water, sand media, a filtration rate of 25 m/h and PAC coagulant. The results are shown in Table 2.

The expected benefit of coagulant was confirmed although the percentage reductions were slightly lower than those obtained with the larger pilot plant at the Wales National Pool. This was thought to be due to the difficulty of dosing smaller amounts of coagulant.

Table 2. Sand filtration results using the smaller pilot plant and tap water

Run No.	Coagulant Dose PAC mg(Al)/l	pH	Tank 1 Mean Count/ml (filter inlet)	Tank 2 Mean Count/ml (filter outlet)	Mean % Removal
1	0	7.2	6.71E+04	4.53E+04	**32.5**
2	0	7.2	9.29E+04	5.58E+04	**40.0**
3	0	7.0	8.16E+04	6.65E+04	**18.4**
4	0	7.0	1.30E+05	6.80E+04	**47.8**
5	0.05	7.1	8.14E+04	1.46E+04	**82.0**
6	0.05	7.2	4.73E+04	3.33E+03	**92.9**
7	0.05	7.2	6.20E+04	4.46E+03	**92.8**
8	0.05	7.2	5.39E+04	3.21E+03	**94.0**

In 2008, the large pilot plant was used on real pool water with both sand and crushed glass (AFM) media for a range of operating conditions. The particle loading was between two and three times higher than for the runs shown in Tables 1 and 2. The results summarised in Table 3 again demonstrated the benefit of dosing a coagulant. With coagulant, the percentage removals were generally slightly lower than those achieved in 2007, possibly a reflection of the higher particle loadings. Without coagulant, the percentage removals achieved by glass were slightly lower than those achieved with sand and, with coagulant addition, the removal efficiencies observed with glass were slightly lower than sand in five of the six mean value comparisons. The number of experimental runs is, however, too small for meaningful statistical analysis.

Table 3. Comparison of sand and AFM glass filtration media

	% Removal of Surrogate Particles							
	25m/h				50m/h			
	Sand		Glass		Sand		Glass	
Coagulant	**Runs**	**Mean**	**Runs**	**Mean**	**Runs**	**Mean**	**Runs**	**Mean**
None	61,90	**55.9**	34,20	**52.7**	74,40	**68.5**	32,10	**45.2**
	50,00		64,60		62,50		58,30	
			59,20					
PAC 0.05mg/l (Al)	93,20	**92.5**	92,00	**93.5**	89,50	**92.7**	86,60	**85.8**
	97,10		94,80		95,90		84,94*	
	87,22		93,80					
PAC 0.005mg/l (Al)	95,20	**91.1**	89,30	**83.9**	80,00	**76.8**	77,81*	**76.3**
	87,00		80,10		73,50		74,74*	
			82,30					
Alum 0.01mg/l (Al)	91,50	**92.9**	64,80	**75.9**	93,70	**80.0**	63,00*	**76.8**
	94,20		80,70		66,30		90,52*	
			82,10					

* due to equipment failure, a different microscope was used to count the particles – the two results for glass at 50 m/h with 0.005 mg/l (Al) PAC were comparable, suggesting that the change in microscope was of no significance

A second filtration trial in 2008 was undertaken using the large pilot plant that sought to compare the performance of DMS glass media with sand. The particle loadings were similar to the earlier trials in 2008 (around 1.5x105 per ml) and used PAC and a filtration rate of 25 m/h. The summary results shown in Table 4 again show a clear benefit of adding coagulant and that particle removals are better at the higher coagulant dose.

Table 4. Comparison of sand and DMS glass filtration media

Nominal PAC dose mg/l (Al)	% Particle removal by sand	% Particle removal by DMS glass media
0	29	34
0.005	63	43
0.05	94	99

Filtration results for *Cryptosporidium oocysts*

The small pilot plant has been used with sand media and a filtration rate of 25 m/h for both live and inactivated oocysts. In both cases, the loading of oocysts onto the filter was much lower, in the range 25 to 38 per ml. The results are summarised in Table 5.

Table 5. Sand filtration of live and inactivated *Cryptosporidium oocysts*

(a) Live oocysts

Number of runs	Nominal PAC dose mg/l (Al)	Oocysts per ml filter inlet	Oocysts per ml filter outlet	Average % Removal
6	0	25	1.513 to 3.870	89.6
6	0.05	25	0.003 to 0.008	99.9

(a) Inactivated oocysts

Number of runs	Nominal PAC dose mg/l (Al)	Oocysts per ml filter inlet	Oocysts per ml filter outlet	Average % Removal
2	0	33.4 to 38.0	0.137 to 0.201	99.5
2	0.05	26.6 to 33.4	0.016 to 0.031	99.9

Again, the results demonstrate the benefit of dosing coagulant. However, the difference between filtration with and without coagulant addition is much less pronounced at the considerably lower oocysts loadings that were applied.

Surface charge properties

Figures 2 to 5 show the measured zeta potentials of surrogate particles and inactivated oocysts at 0.001 and 0.01 molar salinities, for a range of pH conditions. An isoelectric point for the particles/oocysts can be determined by extrapolating the data to the pH when the particles/oocysts have a net electroneutrality and their overall surface charge is zero.

Figure 2. Zeta potential of surrogate particles at 0.001 molar salinity

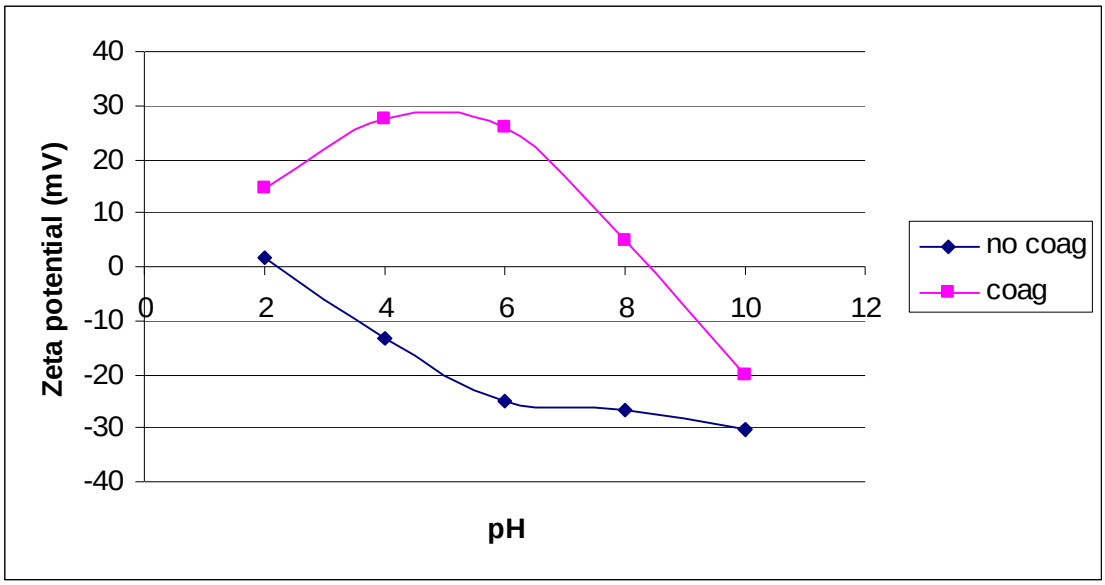


Figure 3. Zeta potential of inactivated oocysts at 0.001 molar salinity

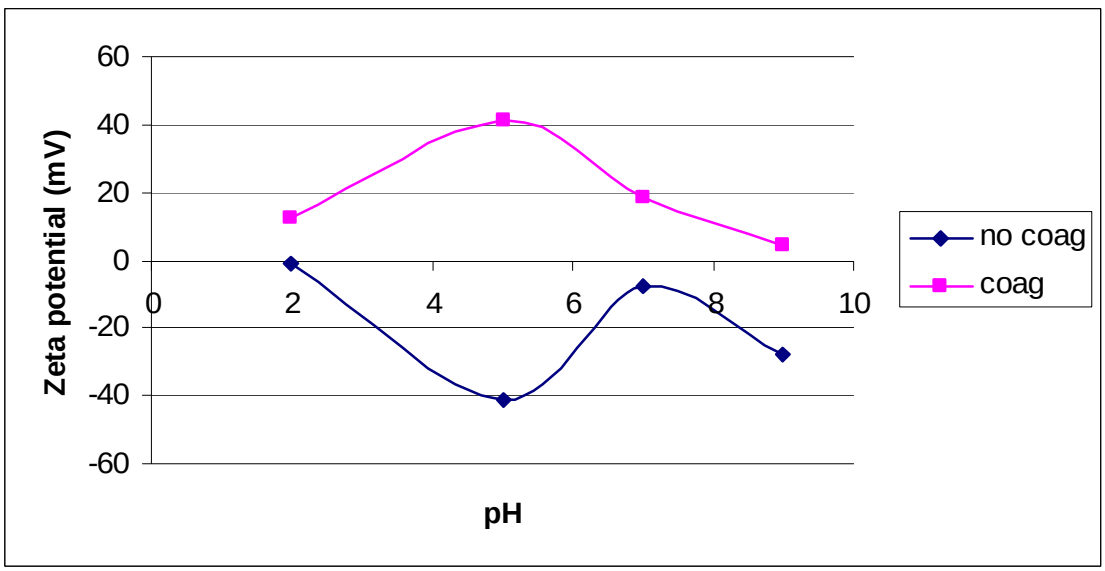


Figure 4. Zeta potential of surrogate particles at 0.01 molar salinity

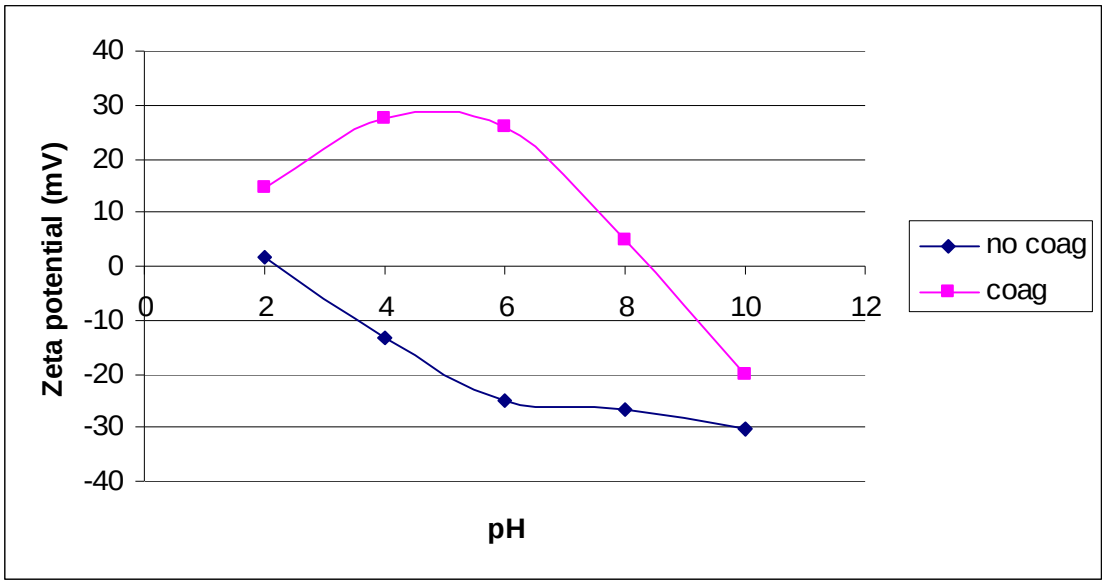


Figure 5. Zeta potential of inactivated oocysts at 0.01 molar salinity

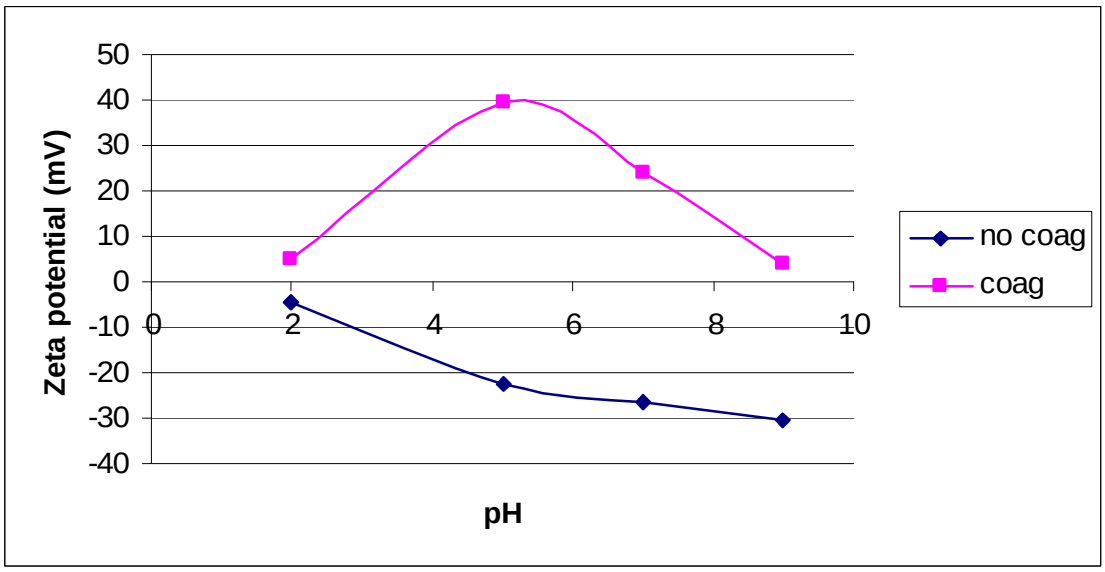


Table 6 shows the isoelectric points that were determined for the full range in ionic strength (molar salinity) that was investigated, with and without coagulant. Where coagulant was added, PAC was added at 0.05 mg/l (Al).

Table 6. Summary of isoelectric points determined for surrogate particles and inactivated oocysts.

	Ooocysts		Surrogates	
Ionic strength	No Coag	Coag	No Coag	Coag
0.1	3.2	9.1	3.5	7.2
0.01	1.6	9.2	3	8.5
0.001	1.9	9.5	2.2	8.5
0.0001	1.5	9.5	2.1	8.5

It can be concluded that under typical pool water conditions (0.001 to 0.01 molar salinity) coagulant addition significantly alters the charge of the particles/oocysts at the pH values approaching those experienced in practice. At a pH of 7.5 to 8.0, without coagulant the particles/oocysts have a negative surface charge. Such particles/oocysts can be expected to be repulsed by the negative surface charge of the filtration media, explaining their poor removal. At this range of pH and with coagulant added the particles/oocysts have a positive surface charge. Such particles/oocysts can be expected to be attracted by the negative surface charge of the filtration media under the experimental conditions used, and the coagulated particles/oocysts are larger, both explaining their much better removal by filtration.

Conclusions

In the high rate filtration of swimming pool waters, the removal of high loadings of surrogate particles are much improved by the addition of coagulant, 99% removal being possible.

The removals of live and inactivated Cryptosporidium oocysts, at much lower loadings, were also enhanced by coagulant addition with >99% removal achieved.

The better performance when coagulant is added is explained by a surface charge effect, with the negative charge of particles/oocysts being changed to positive, thereby overcoming repulsion by negatively charged filtration media, and the better physical removal of the larger coagulated particles/oocysts.

Crushed glass and sand media were found to be broadly similar in the removal of surrogate particles, under the experimental conditions used.

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