Check for updates

Water Science and Technology: Water Supply **Vol 2 No 5–6 pp 301–306** © IWA Publishing 2002

Coagulation as a pretreatment of SFBW for membrane filtration

A. Nasser*, Z. Huberman*, L. Dean, F. Bonner** and A. Adin****

* Water Quality Research Laboratory, Ministry of Health, P.O.Box. 8255, Tel-Aviv 61082, Israel
(E-mail: *abidnasser@phlta.health.gov.il*)

** Division of Environmental Sciences, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

Abstract Granular filtration has been incorporated as a major barrier to prevent the dissemination of disease-causing agents by drinking water. Particles and pathogens such as *Giardia lamblia* and *Cryptosporidium parvum* retained in the filters are then washed by utilizing clean water. This study was conducted, primarily, to evaluate coagulation as a pretreatment for the Spent Filter Backwash Water (SFBW) treatment by ultrafiltration (UF). SFBW Samples were collected from four different water treatment plants and carefully analyzed. Jar-tests and backwash pilot studies were performed in the laboratory. Depending on the water source, protozoan parasites and viruses were found to be prevalent in SFBW. The results show that turbidity cannot serve as a surrogate for the microbial load of the SFBW. Alum flocculation pretreatment of SFBW was found to be effective in reducing turbidity, particle count, viruses and parasites, consequently it may also reduce membrane fouling. Settling the SFBW prior to flocculation did not enhance the removal of turbidity and particle count as compared to the unsettled SFBW samples. This finding might imply that settling would not be required prior to UF. The largest remaining particle fraction after alum flocculation was 3–10 μm in size, both *Cryptosporidium* and *Giardia* are found in this size range. Coagulation enhanced the removal of small size particles and may result in extending the filtration cycle by reducing the SFBW fouling potential.
Keywords Coagulation; *Cryptosporidium*; membrane filtration; NOM; recycle; SFBW

Introduction

Treatment of surface waters by granular filtration has long been recognized as a major barrier to the spread of disease-causing agents by drinking water. High rate filtration has been found to be efficient for the removal of polioviruses and hepatitis A virus from surface waters (Nasser *et al*., 1995). Granular filtration has been incorporated as major treatments phase in surface water treatment, especially, for the removal of cysts and oocysts of *Giardia lamblia* and *Cryptosporidium parvum*. These protozoan parasites have been found to be insensitive to the traditional disinfection methods used in the water industry (LeChevallier and Norton, 1995). Materials retained within granular filters during filtration (i.e. organic and inorganic particles, bacteria, viruses and parasites) are removed by back-washing the filter with clean water. The resulting water, which was pushed back through the filter in the cleaning process, is referred to as spent filter backwash water (SFBW). The SFBW contains high concentrations of particles that were trapped in the filter during operation, including coagulants, metals and microbes such as *Cryptosporidium*. Studies have documented a range of *Cryptosporidium* oocyst concentration in SFBW from non-detects to over 15,000 oocysts/100 l (Environmental Engineering and Technology, Inc., 1999).

The volume of the SFBW generated is typically between 3–7% of the finished water produced and it is often discharged to the sewage system or recycled within the treatment plant. Recycling practice should be conducted in a manner that does not upset the chemical treatment and coagulation processes vital to the performance and contaminant removal capability of a filtration plant. Treatment plants must ensure that *Cryptosporidium* oocysts in recycled water as well as source water are subject to well operated treatment processes to achieve at least a 2-log *Cryptosporidium* removal. If the recycling flow is not adequately

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/301/407718/301.pdf
by guest

treated before being returned to the primary treatment train, significant numbers of oocysts captured during a filter run will be returned to the plant. These oocysts are again loaded onto the filters increasing the risk that disinfectant-resistant pathogens such as *Cryptosporidium* can slip through filtration, thereby posing a public health risk. SFBW recycling was regulated recently by the USEPA to prevent overloading of the filtration processes by disease causing pathogens (USEPA, 2001).

Membrane systems offer the water supply industry with a potentially more reliable and effective treatment (Adham *et al*., 1998). Membrane processes can help utilities meet stringent requirements for turbidity, disinfection by-products (DBPs), and microbiological organisms (*Giardia*, *Cryptosporidium* and viruses). The physical removal of microorganisms means less disinfection is required, in turn, reducing DBP formation. Water treatment plants may use integrated membrane systems (IMS) to remove organic matter, pesticides, taste and odor compounds (Adham *et al*., 1998).

This study was performed to determine the effect of alum coagulation on the reduction of parasites, organic material and turbidity from SFBW. Furthermore, the physico-chemical and microbial quality of SFBW from surface water and swimming pools treatment plants was determined. The effect of coagulation on the performance of the ultra-filtration process of SFBW was also evaluated.

Materials and methods

SFBW sources

Spent filter backwash water (SFBW) was collected from four different water treatment plants and analysed for microbial and physical parameters. Two of the plants sampled are drinking water treatment plants and two are filter plants treating swimming pool water. It was anticipated that the swimming pool SFBW might have a "richer" microbiological matrix compared with water from the other plants. The drinking water plants all treat surface water, either from the Jordan River or from Lake Kinneret (the Sea of Galilee). For all the plants sampled backwash was initiated after a specified time interval (typically 24 hours). However, as not all of the filters were operated continuously, actual filter run time varied between 6 and 18 hours. Other operational differences between the plants included coagulant dose; pH adjustment chemicals and addition points for disinfectant; filter loading rate; and backwash length and flow.

Methods for microbe detection and enumeration

SFBW samples were collected in sterile bottles and transported to the laboratory on ice in a cooler. Fecal coliforms were enumerated by the MPN method (APHA *et al*., 1999). Cultivation and enumeration of Cox A9 virus was performed in BGM cell as previously described (Nasser *et al*., 1993). Naturally occurring enteroviruses in SFBW samples were detected by the production of cytopathogenic effects in the BGM cells (Straub *et al*., 1995). Naturally occurring bacteriophages were enumerated by the double-layer method on a loan of *Salmonella typhymurium* WG-49 (Adams, 1959). One litre samples of SFBW were concentrated and processed for the detection of parasites as previously described in Rule 1623 of the USEPA (US EPA, 1999). Concentrated samples were stained by an indirect fluorescent assay using the Meridian kit (Meridian Diagnostics, Cincinnati, OH). Parasite cysts and oocysts were counted and identified using an epifluorescent microscope. Detection of *Cryptosporidium* in natural samples was confirmed by the Polymerase Chain Reaction (PCR) (Rochelle *et al*., 1997).

Physical and chemical characterization of SFBW

SFBW samples were collected in 20 l containers and transported to the laboratory within 2 hr, where they were refrigerated at 4°C. Turbidity and pH measurements were taken

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/301/407718/301.pdf
by guest

every minute over the course of the backwash run. SFBW samples were analysed for turbidity, pH, TSS, DOC, UV-254 absorbance and alkalinity. All analyses were conducted as specified in *Standard Methods* (APHA *et al*., 1999).

Jar test studies

The jar tests were conducted on a Phipps and Bird apparatus with 2 L B-Ker 2 square jars. Rapid mix at 150 rpm for one minute was followed by a 20 minute flocculation period at 30 rpm. Alum was added from a 10 g/L solution at concentrations of zero up to 40 mg/L. Turbidity measurements were taken 2 minutes, 10 minutes and 20 minutes after flocculation ended. At 20 minutes, samples were also analysed for UV 254 nm, DOC, total particle count (TPC) and size distribution (PSD), alkalinity and pH. Jar tests were also conducted on SFBW samples spiked with *Cryptosporidium parvum* and Cox A9 Virus at a dose of 40 mg/L alum. After settling for 20 minutes, samples were taken and analysed for turbidity, DOC, UV-254 nm, total particle count and size distribution, *Cryptosporidium* and Cox A9 content.

Membrane unit

The membrane unit used in this study is a hollow-fiber immersed membrane manufactured by Zenon Corp. The unit is a ZeeWeed-10 with a molecular weight cutoff of approximately 200,000 kDa. The unit operates on a vacuum with a typical range of 0.1 to 1 bar. This system has a backwash frequency of approximately 4 to 6 backwashes per hour and can produce approximately 20 litres/hour of permeate.

Results and discussion

Microbial and physico-chemical characterization of SFBW (see Table 1)

The turbidity of SFBW of all sampled plants was very high in the first minute and then decreased rapidly. Turbidity values of up to 1,000 NTU were measured during the first minute of the filter backwash. Although, the turbidity value of the first minute was higher in SFBW of lake samples than in stream samples, greater values were recorded for fecal coliforms in stream samples, indicating that the turbidity does not correlate with the microbial quality of SFBW. Cultivable enteroviruses were detected in 3 out of 3 (100%) stream SFBW samples and in 2 out of 3 (66%) SFBW lake samples. Male-specific bacteriophages were also detected in 2 out of 2 samples analysed from each site. *Cryptosporidium* was more prevalent than *Giardia* in samples from both stream and lake treatment plants, where 5 out of 6 SFBW samples were found positive for *Cryptosporidium*, whereas 2 out of 4 samples were found positive for *Giardia* cysts. Three out of 6 samples were found to be positive for *Cryptosporidium* by the polymerase chain reaction technique. Since the oocysts of *Cryptosporidium* were concentrated and purified by immunomagnetic separation (IMS) it is highly possible that the detected oocyts are viable (Deng *et al*., 1997). SFBW samples from swimming pools were found negative for fecal coliforms. *Giardia* cysts were detected in 1 out of 3 SFBW samples and the same ratio was determined for *Cryptosporidium*.

There was considerable variability recorded in the physico-chemical quality of SFBW samples from the different drinking water treatment plants due to differences in raw surface water qualities and operational practices. The highest variability was recorded for TSS and turbidity, 46–384 mg/l and 28–370 NTU, respectively. In comparison, lower variability was observed in the concentration of organic material in the SFBW (composite DOC ranged between 1.7–8.7 mg/l). The values detected for *Cryptosporidium* in the SFBW in stream and lake water samples are similar to those reported previously by Di Giovanni *et al*. (1999). They reported mean concentration of 190 oocysts/100 l. In this study the concentration of oocysts ranged between 25 to 300 oocysts/100 l. No correlation was observed between turbidity values and microbial quality of SFBW, indicating that turbidity in SFBW

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/301/407718/301.pdf
by guest

Table 1 Microbial and physico-chemical characterization of SFBW

Parameter		Sampling site			
		Tiberias (lake)	B. Hillel (stream)	Kinar (lake)	Yamit[6]
Turbidity NTU[1]		50–168	60–174	400–548	18–210
F. coli		23–900	500–1,600	2–4	0.0
Cfu/100 ml		(2/2)[3]	(3/3)	(3/3)	
Entero-viruses		ND[7]	(3/3)	(2/3)	ND
Phages[2]		0.0	(2/2)	(2/2)	0.0
Giardia	FITC[4]	0–12	0.0–0.25	0–0.5	0–2.0
	cysts/l	(1/2)	(1/2)	(1/2)	
Crypto	FITC	0–4	0.25–1.25	0.6–3.0	0–0.05
	Oocysts/l	(2/3)	(2/3)	(3/3)	
	PCR[5]	ND	(2/3)	(1/1)	ND
DOC (mg/l)*		3.49–3.86	1.7–3.2	3.2–8.7	3.56
TSS (mg/l)*		92–266	46–55	106–384	ND

1 – Turbidity in the first minute of backwashing; 2 – Male-specific bacteriophages; 3 – Prevalence ratio; 4 – Monoclonal antibodies labeled with FITC; 5 – Detection by polymerase chain reaction; 6 – Swimming pool samples; 7 – No data. * Results of composite SFBW samples

does not originate necessarily from human activities. It seems that disinfection is responsible for the reduction of the microbial load in SFBW from swimming pools.

Removal of *Cryptosporidium* and Cox A9 virus by alum coagulation

Allowing the SFBW to settle for one hour resulted in a significant reduction in the suspended solids and turbidity values. Jar-test without alum addition showed a reduction of 87% in the turbidity for the SFBW sample, whereas only 20% reduction was observed for the settled SPBW (data not presented). Figure 1 presents the results of turbidity and TPC from SFBW and settled SFBW following alum flocculation in jar test. The optimal alum dose for turbidity removal was found to be 30 mg/l. Addition of 30 mg/l alum resulted in negligible difference between the removal of particles from both sample types. Following alum coagulation (30 mg/l) the turbidity of was reduced by 98% and that of the settled was reduced by 93% and turbidity values of 1.1 NTU and 0.75 NTU were recorded, respectively. The settled SFBW samples contained mostly stable particles, which did not aggregate and consequently settled poorly. In comparison, SFBW samples contained unstable particles, which enhanced the turbidity removal by flocculation. However, it is worth noting that the SFBW shows good settleability even without alum addition. Most of the remaining particles in the SFBW samples are in the size range of 3–10 μm, which includes the size range of oocysts *Cryptosporidium* and *Giardia* cysts.

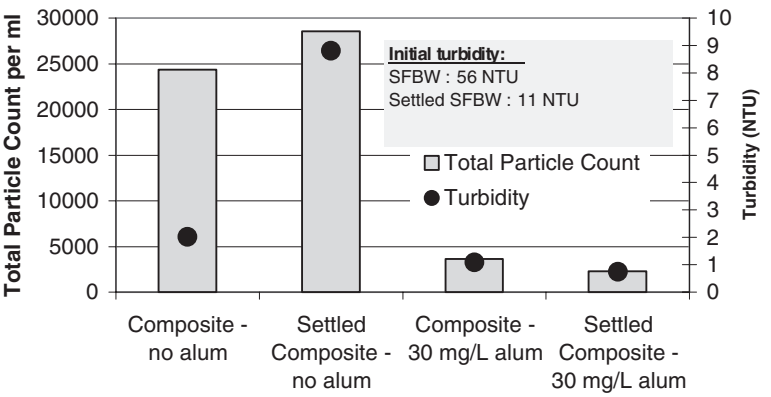

Figure 1 Effect of settling and alum coagulation on the removal of particles from SFBW

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/301/407718/301.pdf
by guest

Jar-tests were performed to determine the removal efficiency of turbidity, *Cryptosporidium* oocysts and Coxsackie A9 virus by alum coagulation (Figure 2). Coxsackie A9 virus (10^5 pfu) and *Cryptosporidium* (10^4–10^5 oocysts) were seeded into composite SFBW samples (turbidity 145 NTU) and coagulation was conducted with 40 mg/l alum. Reductions of 93% were observed for turbidity and *Cryptosporidium* and of 73% for Cox A9. Alum coagulation resulted in significant improvement of the SFBW microbial and physico-chemical quality. Pre-treatment of SFBW by alum coagulation may improve the removal efficiency of NOM, parasites and viruses by membrane filtration. Furthermore, coagulation of SFBW may prevent membrane fouling by particles and natural organic matter (NOM); consequently coagulation may extend the period of filtration cycle.

Retardation efficiency of *Cryptosporidium* oocysts and MS2 bacteriophage from SFBW by ultrafiltration (UF)

To evaluate the retardation of microbes by Ultrafiltration (UF), a hollow-fiber immersed membrane (Zeeweed-10) unit (production 20 l/hr) with a molecular weight cutoff of approximately 200,000 D was applied for the removal of MS2 bacteriophage (25 nm) and *Cryptosporidium* (4–6 μm). Filtration of tap water seeded with *Cryptosporidium* and MS2 bacteriophage through UF membrane resulted in 99.98% removal of *Cryptosporidium*, while negligible removal was recorded for MS2 bacteriophage. Coupling alum coagulation with UF membrane filtration resulted in up to 99.66% removal of MS2 bacteriophage, indicating that alum coagulation improves the retardation of MS2 bacteriophage from SFBW.

The Zeeweed-10 system was operated for a two weeks period for SFBW recycling from the drinking water treatment plant of the city of Tiberias (Table 2). The parasites *Cryptosporidium* and *Giardia* were detected once in the SFBW and in the water source, however both were below the detection limit in the permeate. *E. coli* was detected at a concentration of 900 cfu/ml in the SFBW and was found to be below the detection limit in the permeate. It is also worth noting that the total bacterial count (TPC) did not increase appreciably in the SFBW concentrate, which was held for two weeks.

The results of this study indicate that the microbiological and physico-chemical qualities of SFBW depend on the water source and on the treatment practices. Coagulation/flocculation reduce the microbial and particle loading of SFBW thus contributing to improved quality and reduced fouling potential of the UF membrane. Figure 2 shows a greater than 80% removal of both turbidity and particle counts for SFBW treated with alum. Efficient retardation of MS2 bacteriophage by UF suggests that water quality can be highly improved and could be utilized for various purposes.

Conclusions

1. SFBW microbial and physico-chemical quality depends on the quality of the water source and the treatment processes.

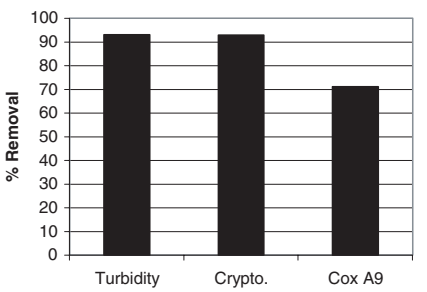

Figure 2 Removal of turbidity, *Cryptosporidium* oocysts and Cox A9 from SFBW by alum coagulation

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/301/407718/301.pdf
by guest

Table 2 Characterization of Kinneret water, SFBW, Permeate and water backwash after UF

Water source	*Giardia* (cysts/25L)	Crypto (oocysts/25)	*E. coli* (CFU/ML)	TPC (CFU/ML)
Permeate	0	0	0	ND
Kinneret	0	2	0	ND
SFBW*	4**	0	900	5×10^5
Concen. of 2 weeks	ND	ND	80	7×10^5

* Spent filter backwash; ** 250 ml sample

2. Alum coagulation could serve as an essential pre-treatment for the reduction of turbidity and microbial load of the SFBW.
3. Alum coagulation enhances the removal of small size particle (viruses) by ultrafiltration.
4. Application of coagulation may extend the filtration cycle through the reduction of the SFBW fouling potential.

Acknowledgements

This study was supported by the German Ministry for research and by the Israeli Ministry of Sciences and Technology. The Authors thank Uri and Zeav from Amiad Filtration Systems, Kibbutz Amiad and Shimon Rosh from Mekorot for their help in sample collection.

References

Adams, M.H. (1959). *Bacteriophages*. Wiley Intersciences, New York.

Adham *et al*. (1998). Prediction and Verification of the performance of powdered activated carbon for removal of organic compounds in the PAC/UF process. *J. AWWA*, **83**(12), 81.

APHA, AWWA, and WPCF (1999). *Standard Methods for Examination of Water and Wastewater*. 19th ed. Washington, D.C:APHA.

Deng, M.Q., Cliver, D.O. and Mariam, T.W. (1997). Immunomagnetic capture PCR to detect viable *Cryptosporidium parvum* oocysts from environmental samples. *Appl. Envir. Microbiol*., **63**, 3134–3138.

Di Giovanni, D.G., Hashemi, F.H., Show, N.J., Abrams, F.A., LeChevallier, M.W. and Abbaszadegan, M. (1999). Detection of infectious *Cryptosporidium parvum* oocysts in surface and filter backwash water samples by immunomagnetic separation and Integrated cell culture-PCR. *Appl. Environ. Microbiol*., **65**, 3427–3432.

Environmental Engineering and Technology, Inc. (1999). Background Papers on Potential Recycle Streams in Drinking Water Treatment Plants. AWWA 73 pp.

LeChevallier, M.W. and Norton, W.D. (1995). *Giardia* and *Cryptosporidium* in raw and finished water. *J. AWWA*, **87**, 54–68.

Nasser, A.M., Tchorch, Y. and Fattal, B. (1993). Comparative survival of hepatitis A virus, poliovirus 1, F bacteriophage, *E. coli* in waste and groundwater. *Water Science and Technology*, **27**, 401–407.

Nasser, A., Weinberg, D., Dinoor, N., Fattal, B. and Adin, A. (1995). Removal of Hepatitis A virus (HAV), poliovirus and MS2 coliphages by coagulation and high rate filtration. *Wat. Sci. Tech*., **31**, 63–68.

Rochelle, P.A., De Leon, R. and Wolfe, R.L. (1997). Comparison of primers and optimization of PCR conditions for detection of *Cryptosporidium parvum* and *Giardia* lamellae in water. *Appl. Environ. Microbiol*., **63**, 106–114.

Straub, T.M., Pepper, I.L. and Gerba, C.P. (1995). Comparison of PCR and cell culture for detection of enteroviruses in sludge-amended field soils and determination of their transport. *Appl. Environ. Microbiol*., **61**, 2066–2068.

US EPA (1999). Method 1623: *Cryptosporidium* and *Giardia* in water by filtration/IMS/FA. EPA-821-R-99-006. U.S.Environmental Protection Agency, Office of Water, Washington, D.C.

US EPA (2001). National Primary Drinking Water; Filter Backwash Recycling Rule. *Federal Register*, **66**(111), 31085–31105.

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/301/407718/301.pdf
by guest