

Characterization and destabilization of spent filter backwash water particles

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Abstract Inorganic and organic particles, including bacteria, viruses and parasites, which are retained within a granular filter during surface water filtration, are removed by backwashing the filter with clean water or water and air. The objective of the study was to characterize SFBW and determine its treatability by coagulation. Microbial and physical-chemical characterization of SFBW collected from a number of different water treatment plants was performed. Experiments to determine the impact of coagulation/flocculation on the SFBW samples were also conducted. SFBW was collected from six different water treatment plants and analyzed for microbial and physical parameters. Physical characterization was done on SFBW collected from all of the treatment plants. Turbidity and pH measurements were taken over the course of the backwash run, and the backwash samples were collected in two to four 20 L containers. A number of parameters were measured for the samples in each container, as well as for SFBW composites made by mixing equal portions of the container contents. The measured parameters included: turbidity, pH, TSS, DOC, UV-254 and alkalinity. Jar tests were carried out on individual containers, on SFBW composite and on SFBW composite that was allowed to settle for one hour. Turbidity and particle count data was collected for both settled and filtered samples.

Keywords Filtration; particle removal; pathogens; spent filter backwash water (SFBW); surface water treatment

Introduction

Surface water must be treated prior to being supplied for potable consumption in order to ensure it is safe and pleasing to drink. The US Environmental Protection Agency (USEPA) has recognized that disinfection alone is not always adequate to sufficiently reduce the risks presented by waterborne pathogens. The Surface Water Treatment Rule (SWTR) was promulgated as a response to the risks presented by disinfectant resistant pathogens such as *Giardia L.* and *Cryptosporidium parvum*. It requires, with few exceptions, the filtration of all surface water supplies as part of the treatment process. Filtration improves water quality through the removal of suspended and dissolved material such as organic and inorganic solids, viruses, bacteria, protozoan parasites, and dissolved organic matter. A properly operated filtration process, in conjunction with disinfection, has been established as the best means of providing safe water. When a filter is backwashed the organic material, inorganic particles and microorganisms captured during filtration are removed from the filter in the spent filter backwash water (SFBW). The volume of 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. The exact quality of the SFBW depends on the level of contamination of the source water, the treatment process, and the backwash operation. Therefore, SFBW may contain low levels of contamination, which makes it suitable for drinking water production with minimal treatment requirements. However, SFBW can contain high levels of pathogens and other undesirable material, and may impair the effectiveness of the treatment plant, if it is recycled or pose a public health risk if otherwise used without treatment.

Materials and methods

SFBW sources

Spent filter backwash water (SFBW) was collected from six different water treatment plants (Table 1) and analyzed for microbial and physical parameters.

Three of the drinking water plants and the Givat Ram swimming pool plant are in-line filtration plants using pressurized filters with anthracite/sand media. The Tiberias plant is a direct filtration plant with a pressurized sand filter, followed by GAC columns. The Yamit 2000 swimming pool plant uses diatomaceous earth filters. 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 21 hours. Other operational differences between the plants included coagulant (alum) dose; pH adjustment chemicals and dose; type, doses of, and addition points for disinfectant; filter loading rate; and backwash length and flows.

Methods for microbes detection and enumeration

Filter backwash water samples were collected in sterile bottles and transported to the laboratory on ice in a cooler.

Fecal coliform in the filter backwash samples was enumerated by MPN method (*Standard Methods*, 1999). Because of high turbidity in the samples, the membrane filtration method was not used.

Cultivation and enumeration of Cox A9 virus was performed in BGM cell line as previously described (Nasser *et al.*, 1993). Detection of naturally occurring enteroviruses in SFBW samples was accomplished by the production of cytopathogenic effects in the BGM cell line (Straub *et al.*, 1995). Naturally occurring bacteriophages were enumerated by the double-layer method in a loan of *Salmonella typhimurium* 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. Concentrated samples were stained by an indirect fluorescent assay using the Meridian kit (Meridian Diagnostics, Cincinnati, OH). Parasite cysts and Oocysts were enumerated and identified using an epifluorescent microscope.

Detection of *Cryptosporidium* in natural samples was confirmed by Polymerase Chain Reaction (PCR) procedures (Rochelle *et al.*, 1997).

Physical and chemical characterization of SFBW

SFBW samples were collected in 20 L containers and transported to the laboratory and refrigerated at 4 degrees C. Turbidity and pH measurements were taken every minute over the course of the backwash run.

In the laboratory, a number of parameters were measured for the samples in each container, as well as for SFBW composites made by mixing equal portions of the container contents. It was found that the much of the suspended material in the SFBW settled to the bottom of the container during transport and storage. In order to ensure consistent

Table 1 Treatment plants sampled

Name of plant	Raw water source	Media	Filter flow (m ³ /hr)
Bet Hillel	Jordan River	Anthracite/sand	4.5 to 6
Kinar	Lake Kinneret	Anthracite/sand	60
Tiberias	Lake Kinneret	Sand or Anthracite/sand	180
Bet Yosef	L. Kinneret Reservoir	Anthracite/sand	50
Yamit 2000	Swimming Pool	Diatomaceous E.	3
Givat Ram	Swimming Pool	Anthracite/sand	n.d.

measurements, all samples were gently agitated prior to measurements and testing. The parameters measured included: turbidity, pH, TSS, DOC, UV-254 absorbance and alkalinity. All analyses were conducted as specified in *Standard Methods* (AWWA, 19th Edition).

Jar test treatment studies

Jar tests or modified jar tests were carried out on the contents of the individual containers, on SFBW composite and on SFBW composite that was allowed to settle for one hour prior to the jar testing. The jar tests were conducted on a Phipps and Bird apparatus with 2-L B-Ker² 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 gm/L solution dosed at concentrations of zero up to 50 mg/L. Turbidity measurements were taken 2 minutes, 10 minutes and 20 minutes after flocculation ended. At 20 minutes, samples were also taken and analyzed for UV 254 nm, DOC, total particle count (TPC) and size distribution (PSD), alkalinity and pH. The modified jar tests consisted of one additional step. At 20 minutes, an additional 200 ml sample was withdrawn from the jars and filtered through a paper filter (S&S 595). The manufacturer's literature indicates that particles greater than 4 to 7 μm should be retained. However, as the mechanism of particle removal in the paper filter is depth filtration (particles are retained within the paper fibers throughout the filter depth), it is expected that for destabilized suspensions the size of retained particles will be lower. This filtrate was analyzed for turbidity, total particle count and particle size distribution.

One jar test was conducted on SFBW collected from Givat Ram that had been spiked with *Cryptosporidium parvum* and Coxsackie A9 Virus. Five jars were run, one micro-organism blank, one coagulant blank and three at a dose of 40 mg/L alum. After settling for 20 minutes, samples were taken and analyzed for turbidity, DOC, UV-254 nm, total particle count and size distribution, *Cryptosporidium* and Coxsackie A9.

Results

Backwash characteristics

Turbidity and pH along the backwash cycle. The turbidity measurements taken over the course of the backwash run are shown in Figure 1. For all the plants sampled, the SFBW was observed to be very turbid in the first minute, between 100 NTU to >1,000 NTU.

Turbidities rapidly decreased within the next 2 to 3 minutes, and then decreased more gradually until the end of the backwash cycle (to between 10 NTU and 65 NTU). Since each plant operates its filters differently the values differ, although the trend is the same. The pH was relatively stable over the course of the backwash run for all the plants. The average pH of the SFBW for each plant ranged between 7.5 and 8.2.

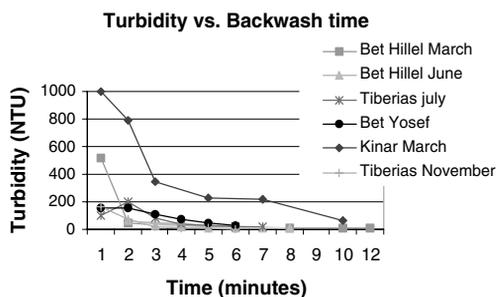


Figure 1 Measured turbidities of the backwash runs

Microbial characterization of SFBW. SFBW samples were analyzed for the prevalence of indicator microorganisms, fecal coliform, F+ bacteriophages, culturable enteric viruses and protozoan parasites (*Cryptosporidium* and *Giardia*) (Table 2). Fecal coliform concentration was greater in SFBW samples from Bet Hillel (500–1,600 MPN/100 ml) than in SFBW of Kinar (2–4 MPN/100 ml). Fecal coliform was not detected in any one of the SFBW samples from swimming pools. 6 out of 6 (100%) SFBW samples from B Hillel and Kinar were found positive for *Cryptosporidium* at a concentration of 0.25–3 Oocysts/litre, whereas *Giardia* cysts were detected in one sample from each site only. Four samples were found positive for *Cryptosporidium* by the Polymerase Chain Reaction (PCR) method. Three were found positive by IF, while one sample was found negative by IF.

Turbidity values of SFBW do not appear to correlate with fecal coliform values. SFBW samples from Bet Hillel plant were found to be positive for culturable enteric viruses. Two out of three SFBW samples from Kinar were found to be positive for culturable enteric viruses. An agreement was observed between the fecal contamination as determined by fecal coliform and the prevalence of pathogenic microorganisms from various groups. F. coliform, *Cryptosporidium* and F+ bacteriophages were undetectable in SFBW samples collected from swimming pools. *Giardia* cysts were detected on one occasion in the swimming pools samples.

TSS, UV-254 nm, DOC. The results for the composite SFBW are shown in Table 3. The TSS of the raw water taken from the lake varied from 2–6 mg/L while the river water contained TSS at a concentration of 32 mg/L. No TSS samples were taken directly from the swimming pools. The TSS concentration in the SFBW was between 46 and 384 mg/L. The DOC concentration in the SFBW was between 1.79–3.56 mg/L.

Treatment of SFBW with and without alum

Jar tests on the individual grab samples and the two composites (pre-settled and unaltered) were conducted to evaluate the optimum coagulation conditions for each part of the backwash. Allowing the SFBW to settle for 1 hour prior to any further tests resulted in a significant reduction of the solids and turbidities. For example, the turbidity of the SFBW collected at Tiberias (July) was reduced from 56 NTU to 11 NTU by allowing it to settle for

Table 2 Microbial and physical characterization of filter backwash water

Date	Sampling site	Turbidity NTU ⁵	Parasites			F.coli Cfu/100 ml	Phages ³	Virus
			Crypto FITC ¹ Cysts/l	PCR ²	Giardia FITC ¹ Cysts/l			
5.6	B. Hillel	–	0.25	ND	–	500	+	+
5.6	Kinar	400	0.6	ND	–	4	+	+
31.7	B. Hillel	60	1.25	+	0.25	1,600	+	+
31.7	Kinar	548	3.0	ND	0.0	2	+	+
18.9	B. Hillel	174	0	+	0	1,600	ND	+
18.9	Kinar	422	2.5	+	0.5	2	ND	–
24.7	Yamit ⁴							
2000	17.9	0.05	ND	0.0	0.0	–	ND	
20.8	Yamit ⁴ 2000	210	0.0	ND	2	0.0	–	ND
27.8	G. Ram ⁴	85.0	0.0	+	0.0	0.0	–	ND
26.11	Tiberias	168	0	ND	3	> 1,000	–	–

1 *Giardia* and *Crypto* stained with monoclonal antibodies labeled with FITC

2 Detection by polymerase Chain Reaction (PCR)

3 Male-Specific bacteriophages detected by WG-49 host

4 Filter Backwash samples from swimming pools

5 Turbidity in the first minute of backwashing

Table 3 SFBW and raw water characteristics

	Turbidity (NTU)	uv-254 nm	SFBW DOC (mg/L)	Raw DOC (mg/L)	SFBW TSS (mg/L)	Raw water TSS (mg/L)
Bet Hillel – March	62	0.013	3.25*	ND	55 ⁺	ND
Bet Hillel – June	28	0.012	1.72	6.0	46	32
Kinar – March	370	0.056	8.74*	ND	384 ⁺	ND
Kinar – June	193	0.045	3.21	2.5	106	5
Tiberias July	56	0.034	3.49	2.8	266	2
Tiberias November	50	0.044	3.86	2.86	92	3
Bet Yosef	72	0.032	3.08	ND	113	6
Givat Ram	145	0.034	3.56	ND	ND	ND

*TOC, ⁺mean value, ND = no data

one hour. Conducting tests on both the composite SFBW and the settled-composite SFBW gave information as to whether there is any differences in the treatment required between the two.

Flocculation with no alum added. There were significant differences observed between the jar test results of the Composite and Settled Composite when no coagulant was added. For the Tiberias (July) treatment plant, there was a reduction of 87 percent in the turbidity for the Composite versus a 20 percent reduction for the Settled Composite. The final turbidities were 7.0 NTU vs. 8.8 NTU, respectively. The results for the other treatment plants showed similar behavior.

The PSD results of the Composite and Settled Composite SFBW from Tiberias (July), after the jar tests, is shown in Figure 2. The values for the Settled Composite are about 15 percent higher compared to those of the Composite. In both cases the biggest size fraction was 5–10 micrometres.

The Settled Composite contained mostly stable particles, which did not aggregate and settled poorly. The Composite, on the other hand, contained unstable particles, which apparently aided in the flocculation and removal of turbidity and particles.

Flocculation with alum added.

(1) Flocculation of grab samples. Jar tests conducted on the individual grab samples indicate that different treatment with alum that is needed during the backwash cycle. Figure 3 shows how the final turbidity and UV-254 values change at a dose of 30 mg/L alum. Both

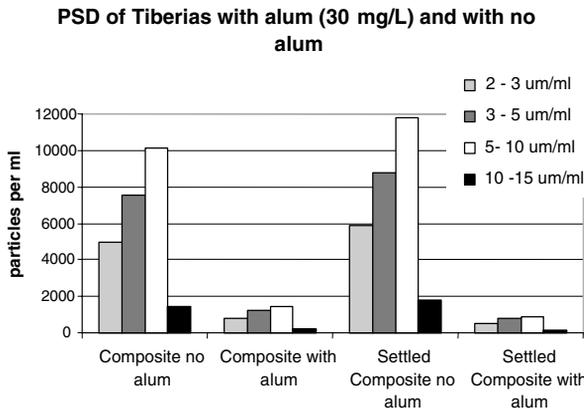


Figure 2 Jar test results, Tiberias (July) – PSD, after 20 minutes settling, Alum 0 and 30 mg/L

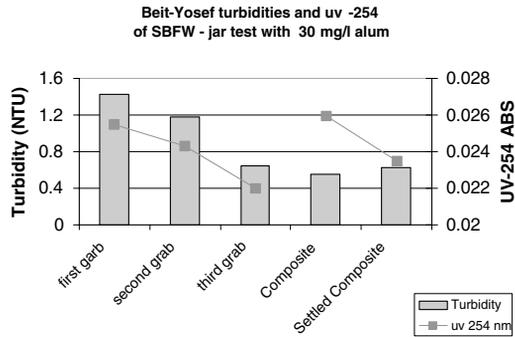


Figure 3 Jar test results, Bet Yosef – turbidity and UV-254 after 20 minutes settling, alum dose 30 mg/L

the final turbidity and UV-254 absorbance results are highest for the first grab sample decreasing to the second and third grab samples. A dose of 30 mg/L was the optimal dose for the composite that was made out of the three grab samples.

(2) Flocculation of the Composites. Alum dose screens were run on each Composite. At an alum dose of 30 mg/L, the turbidity for the Tiberias (July) SFBW was reduced in the Composite by 98 percent and in the Settled Composite by 93%. The final turbidities were 1.1 NTU and 0.75 NTU, respectively. Similar results are shown in Figures 4a and 4b for Tiberias (November). The turbidity and TPC have similar removals at the different alum doses.

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The PSD results for the Composite and Settled Composite SFBW from Tiberias (July), after the jar tests with 30 mg/L alum, are shown in Figure 2. The results for the Composite are about 40 percent higher than the Settled Composite, opposite to what was observed when no alum was added. Again, in both cases the biggest size fraction was 5–10 μm .

(3) Samples spiked with *Cryptosporidium* and Coxackie A9. Jar-tests were also conducted to determine the removal efficiency of turbidity, *Cryptosporidium* Oocysts and coxsackie A9 virus by alum flocculation. Coxsackie A9 virus and *Cryptosporidium parvum* were seeded to a concentration of 10^6 into SFBW (turbidity 145 NTU) from Givat Ram. Coagulation was conducted with 40 mg/L alum. Removals of 93% were recorded for turbidity and *Cryptosporidium* and 73% for Cox A9.

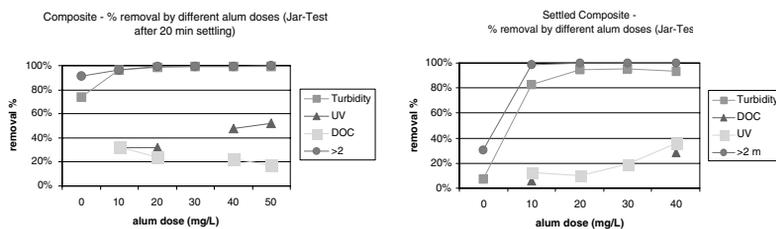


Figure 4a and 4b Jar test results, Tiberias (November) – Percent removal, alum dose screen

Discussion

Comparison of the concentrations between the protozoan pathogens and fecal coliforms, shows that no good correlation between the two exists. Although the fecal coliform counts for the Bet Hillel plant are 2–3 orders of magnitude higher than those of Kinar, there is no similar pattern when the protozoa results are compared. A comparison with the initial turbidity of the SFBW shows that there is also no correlation between it and the microorganism concentration. Nevertheless, the fact that *Cryptosporidium* oocysts are present in filter backwash water in all sampled plants indicates that SFBW treatment should be thoroughly investigated further. A large fraction of the material in the SFBW can be removed by settling with no additional treatment. However, the material that remains appears to be quite stable and requires additional coagulant to enable its removal. It is shown that the coagulant dose required in order to achieve a specific turbidity or TPC is lower when the settleable solids are removed by plain sedimentation. That is to say, the destabilized materials in the SFBW still exert a slight coagulant demand. Also, it is seen in Figure 3 that removing the settleable solids prior to adding coagulant results in a lower organic concentration (represented by UV-254) in the treated water, at the same alum dose. Since the coagulant dose may be lower when the SFBW is “pre-settled”, there may be some benefit to allowing it to occur.

Conclusions

The work conducted allows a number of observations.

1. A part of the suspended material in SFBW is stable. Alum treatment is needed in order to reach low settled turbidity values (~1 NTU) and particles count values.
2. The PSD in the water following the jar tests reveal that the biggest fraction of particles remaining after settling and filtration were in the 5–10 μm size range. The next predominant fraction was the 3–5 μm size range. That these two fractions are the largest remaining is important as this is where both *Cryptosporidium parvum* and *Giardia L.* are found if un-aggregated.
3. The jar test results showed that the overall turbidity removal in the Settled composite was comparable to that of the Composite. However, TPC removal was greater for the Settled composite compared to the Composite. This finding might imply that treating the backwash water would involve mixing with no settling time beforehand.
4. The finding that some of the material removed from the filter media by backwashing could be further destabilized by flocculation, raises an hypothesis that stable colloids, including parasites perhaps, may have been imbedded within the destabilized flocs that formed the filter deposits during the filtration process.

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