

Toxicant and Parasite Challenge of Manz Intermittent Slow Sand Filter

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ABSTRACT: Safe potable water is a luxury that is generally unavailable to the majority of rural and suburban populations of developing, underdeveloped, and often developed countries. Important considerations in the development and maintenance of safe water supplies is the availability and use of efficient, inexpensive, and appropriate technology for removing microbial hazards, parasites, and toxicants. The Manz intermittent slow sand filter was known to be user friendly, small enough to fit into the smallest kitchen, and could remove up to 97% of the fecal coliforms present in the raw water before treatment by the Manz filter. This filter was evaluated for its ability to remove parasitic cysts and toxicants as well as bacteria. Using two different filters and two different water supplies our results indicated that the intermittent slow sand filter could remove 83+% total heterotrophic bacterial populations, 100% of *Giardia* cysts, 99.98% of *Cryptosporidium* oocysts, and 50–90% of organic and inorganic toxicants when administered in concentrations varying from 10– > 100 × environmental pollution levels. Methodology details are provided in the paper. © 1999 by John Wiley & Sons, Inc. *Environ Toxicol* 14: 217–225, 1999

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INTRODUCTION

Safe potable water is a luxury that is generally unavailable to the majority of rural and suburban populations of developing, underdeveloped (WHO, 1981), and often developed countries. Important considerations in the development and maintenance of safe water supplies is the availability and use of efficient, inexpensive, and appropriate technology for assessing microbiological water quality (Castillo, 1992; Dutka and El Shaarawi 1990). Realizing these problems, the International Development Research Centre (IDRC), Ottawa, and the Canadian Federal Departments of Health and Environ-

ment funded international and national projects to train local aboriginal community members to perform microbiological water quality tests on their drinking water (Seidl et al., 1990; Dutka et al., 1990; Seidl and Dutka, 1993; Dutka and Seidl, 1993a,b; Castillo and Etcheberrigaray, 1996).

In some of the communities in developing countries it soon became obvious that all the potable waters being tested were positive for Enterobacteriaceae. This led to the questions, why keep testing, and what can be done about this pollution problem? There was a simple, inexpensive solution to this problem, the intermittent slow sand filter which had been developed by Dr. David Manz, University of Calgary (Lee, 1991; Manz et al., 1993; Buzunis, 1995). The filter is presently being sold by Davnor Water Treatment Technologies Ltd. in

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Calgary, AL under license from University Technologies International Inc. which is wholly owned by the University of Calgary. (Canadian and USA patents pending).

Several of these filters were installed in the Chol-Chol and Maquehue Mapuche communities in Chile, by the IDRC in 1993 and were monitored by the trained Mapuche technicians and the University of Chile (Castillo and Etcheberrigaray 1996). During this same time period a toxicology screening study of potable waters in the Mapuche homelands was initiated (Dutka, 1995). Based on the data obtained from the Dutka (1995) study and the ongoing parallel IDRC-sponsored study on drinking water quality, it became obvious that all the surface and underground waters used directly for drinking, cooking, washing, etc. were not only fecally polluted but also contained toxicants, many of which were pesticides. Both the fecal bacteria and toxicants were serious contaminant problems; however, it appeared that the microbial pollution problem could be and was being solved by the Manz filter but, the toxicants in the potable water problem, were still there. Also there appeared to be no simple inexpensive solution to this problem, in an area where each home had its own water supply, electricity was often unavailable and there were no local funds to assist the residents in obtaining clean safe water. This potential toxicological hazard is believed to be common to all countries (Metcalf, 1973), even those with centrally treated and distributed water supplies.

As a potential low-tech, inexpensive partial solution to this problem, it was decided to evaluate the ability of the Manz filter to remove toxicants through the bioaccumulative and biodegradation ability of the biofilm, the "heart" of the Manz filter. Also, since *Cryptosporidium* and *Giardia* cysts are problems in urban and rural North American communities as well as in other countries (Wells, 1995), it was decided to investigate the ability of the Manz filter to contain the cysts within the biofilm and sand layer, and perhaps provide a degree of safety to those drinking the filtered water. The results of this investigation are documented below.

METHODS

Preparation of Filter Unit

The Manz intermittent slow sand filter unit (the filter) was prepared as shown in Fig. 1. The gravel layer was made up of stones 1–2 cm in size, and on top of this was placed a fine cloth mesh. Water was then poured into the filter to cover the cloth and provide a 5–10 cm overlay. To this was added slowly, fine white, Ottawa quartz sand followed by more water then more sand. Sand was always added to the water until the required sand height was reached. Detailed installation instructions are provided when the filter is purchased (Dawnor Water Treatment Technologies Ltd., 1996; Buzunis, 1995).

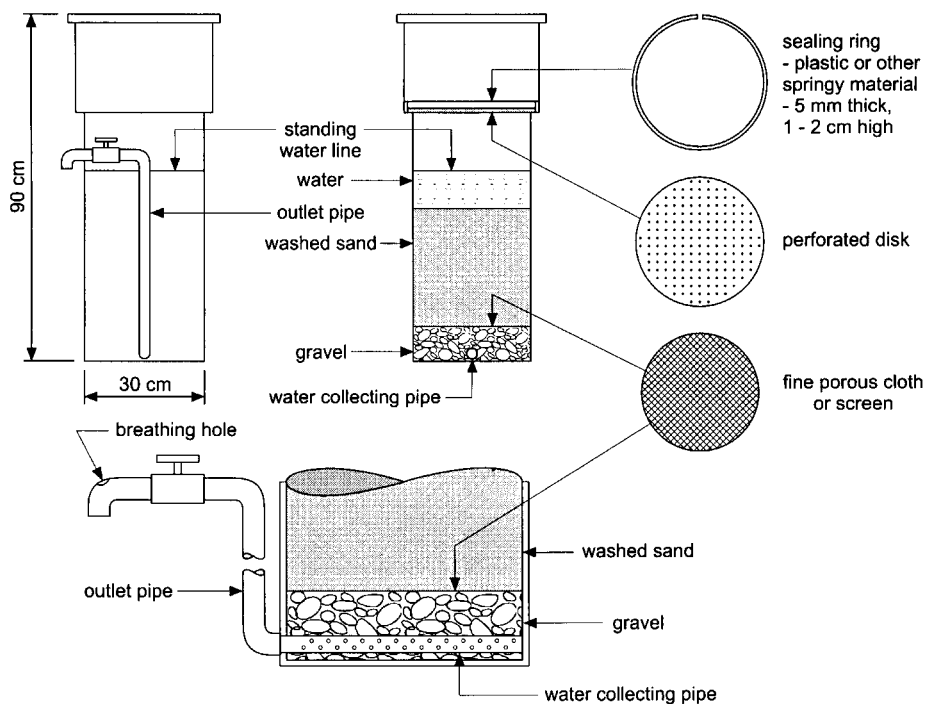


Fig. 1. Manz intermittent slow sand filter.

Two filter units were set up for this evaluation, one at the National Water Research Institute (NWRI) and the other in Calgary, AL. In the NWRI filter (filter #1), relatively clean Lake Ontario water was continuously added to the filter until the clarity of the water coming out of the filter could not be distinguished from tap water. The filter was then fed 25 L of lake water each day for 16 days. At this point no total coliforms or fecal coliforms had been detected in the outflow waters for 3 days. The diffuser screen (perforated disk, Fig. 1) was removed to establish that a biological film had developed and the height of the standing water over the sand. The standing water was 5.6 cm and approximately 85–90% of the surface was covered with a biological layer. Since the filter unit had been maintained at 21–23°C during this period, it was assumed a sufficient biofilm had been formed so that we could start the experiments. The second filter unit (#2) in Calgary was challenged with the more turbid Bow River water until there was an obvious confluent surface biofilm (2 weeks). During this biofilm development period, temperatures varied between 0–20°C.

After biofilm (smutzdecke) development, but before toxicant addition, approximately 3 g of surface sand–biofilm were collected for bioassay testing. During the study two other samples were collected, as well as one at the end of the study.

Chemical Additions

In this study we initially evaluated filter #1's capacity to retain and possibly biodegrade the PAH, phenanthrene (750 µg) and the herbicide, metolachlor (50 µg) which were added in 16 L of lake water on days; 1, 4–8, 11, 13, and 19. Samples were taken for chemical analyses and bioassays on days; 1, 4–8, 11, 13, 19, 22, 27, 33, 40, and 50. The natural lake water was tested for phenanthrene, metolachlor and toxicants on days 1, 4, 11, and 50.

Later in the year filter #1 was again challenged with a chemical toxicant, HgCl₂. For 9 days the filter was challenged with HgCl₂ added in 40 L of Lake Ontario water in Hg concentrations varying from 98.9 to 208 ppb. During this period both input and filtered water were monitored for Hg concentrations with the filtered water being sampled after 39 L of water had passed through the filter. After the last addition of HgCl₂ only 40 L of lake water were added daily to the filter and the filtered waters were monitored for 5 days for Hg concentrations similar to the first 9 days.

Filter #2 was challenged daily with 5 ppm Hg and 10 ppm nonylphenol in 25 L of Bow River water for 21 days. Water samples were collected for bioassays on days 4, 6, 11, 16, and 21. Surface biofilm–sand were also collected for bioassay tests on days 4, 11, and 21.

Chemical Analysis

Phenanthrene and metolachlor concentrations were estimated in the ppb range using commercial immunoassay kits (Quantix and Agri-Diagnostics). The reliability and sensitivity of immunoassays have been well described by Wust and Hock (1992). Analysis of Hg concentrations in filter #1 were performed using the automated cold vapor technique (USEPA, 1974). Input and filtered lake water for filter #1 were also examined for the following: total suspended solids (TSS), Method No. 2540D; 5 day biochemical oxygen demand (BOD₅), Method No. 5210B; chemical oxygen demand (COD), Method No. 5220D; and total organic carbon (TOC), Method No. 5310C (APHA 1995).

Bioassays

Two bioassays were used to screen the lake and river water, the inoculated river and lake water and the filtered water for toxicants. These were; the 48 h *Daphnia magna*, and the 15 min Microtox test (Dutka, 1988). The sediment-chromotest was used to test sand and biofilm samples (Kwan, 1993). Bacteriological tests were only performed on the lake water and filter #1 outlet waters.

Total coliform counts were obtained using mEndo agar and membrane filtration and fecal coliform and *E. coli* population estimates were obtained by the MPN technique using A1 Broth with MUG (Dutka and Seidl, 1993a). Heterotrophic plate counts were obtained using the spread plate technique, Heterotrophic plate count agar and incubation at 20°C for 7 days (Dutka, 1989).

Parasite Additions and Screening

To approximate a typical infrequent assault on the filter by a massive dose of parasitic cysts (e.g., a cow defecating in a stream which is used as a source for drinking water), 10⁶ *Cryptosporidium* oocysts and 10⁵ *Giardia lamblia* cysts were added in 16 L of lake water to the filter. Except for week-end days and holidays every day after this massive inoculum 16 L of Lake Ontario water were added to the filter to maintain the biofilm and to test the efficiency of the filter.

On days 1, 4–8, 11–15, 18–22, 25–28, and 29 the 16 L of filtered lake water were collected into individual containers for cyst enumeration and identification.

All the above samples were transported to the Ministry of Environment Laboratories in London, ON for cyst enumeration following the procedures developed by Aldom and Chagla (1995) which used membrane filtration and dissolution followed by the Merifluor immunofluorescence assay for *Cryptosporidium*–*Giardia*, with one minor modification. To dissolve the

filter 100 mL of DMSO (dimethyl sulphoxide) was used instead of acetone. From ongoing experience DMSO appeared to be less stressful on the oocysts–cysts as they tended to maintain their spherical shape and fluoresced more intensely.

RESULTS AND DISCUSSION

During the biofilm building period using Lake Ontario waters, the maximum total coliform count of input water was 39 per 100 mL with the filtered water maximum being 12 coliforms. Once metolachlor and phenanthrene were added, fecal coliform and *E. coli* MPN tests were conducted on eight input and output samples over 33 days. All counts were less than two per 100 mL with the exception of MPN values obtained on day 19. Here we observed fecal coliform and *E. coli* MPN values of 23/100 mL while the filtered water values were eight fecal coliforms and two *E. coli*/100 mL. From the above, it is obvious that the waters used in the metolachlor and phenanthrene study contained very few coliform-type organisms. When some were found, their removal rate varied between 65 and 90+%. These results were very similar to those reported from Nicaragua by Buzunis (1993) where input waters contained 10 or less fecal coliforms per 100 mL. During this experiment up to day 33, the biofilm was not complete and dense (Fig. 2) due to the lack of pollution (bacterial, algal, and organics) in the input waters.

Surface sand–biofilm samples were collected just prior to toxicant addition from two areas, little biofilm and heavy biofilm on day 50 of the Lake Ontario toxicant addition study. These samples were tested for toxicity by the sediment-chromotest procedure and all samples indicated EC_{100} values > 50% sediment concentration. These data suggest that there was no major retention of toxicants in the surface smutzdecke or that biodegradation was occurring at a sufficient rate to keep the toxicity level below the sensitivity of the bioassay. In contrast the Bow River water filter had a well developed smutzdecke and the Sediment-chromotest results indicated (a) before toxicant addition EC_{100} values > 50% sediment concentration, (b) day 4 of toxicant addition EC_{100} value of 6.25%, (c) day 11 of toxicant addition, EC_{100} value of 3.13%, and (d) day 21 of toxicant addition, EC_{100} value of 0.78%. These data indicate a continuous build-up of toxicants in the smutzdecke an indication that the filter is operating efficiently and is removing toxicants from the spiked waters.

The mean of five heterotrophic plate counts for Lake Ontario input waters were 3360 colony forming units (CFU) per mL while the filtered waters contained

571 CFU per mL. This represents a 83% reduction in heterotrophic bacterial counts which approaches the results of Manz and Buzunis (1995).

The premise on which the Manz intermittent slow sand filter (MISSF) is based, is that the water passes through an undisturbed “smutzdecke” and an aerobic system. The overlying water level depth becomes important in the optimal operation of the MISSF. In filter #1 (lake water) the overlying water depth was 5.6 cm, while the ideal depth is approximately 2.5 cm (Buzunis, 1995). In the future, evaluations on toxicity removal will be carried out with a water overlay depth of 2.5 cm. In filter #2 the overlying water level was in the 2.5–3 cm range.

Table I presents a detailed summary of the results of parasitic cyst additions via Lake Ontario water. *Giardia lamblia* cysts (6–16 μm) were completely retained within the smutzdecke and sand for 29 days, when the experiment ended. These data are compatible with the slow sand filter 100% removal results reported by Bellamy et al. (1985) and Schuler and Ghosh (1991). *Cryptosporidium* oocysts, perhaps due to their smaller size (4–7 μm) showed some breakthroughs up to day 22. From day 22 to day 29 no further oocysts were encountered. Even with the sporadic breakthrough of oocysts and massive initial inoculum, over 99.98% of the *Cryptosporidium* oocysts were retained in the filter. Again these results are equivalent to those observed in slow sand filters (Bellamy et al., 1985; Schuler and Ghosh, 1991).

In a recent review by Kindzierski and Gagos (1996), it was noted that in an experimental feeding trial 16 people were given doses of approximately 300 *Cryptosporidium parvum* oocysts and 14 became infected. Haas and Rose (1995) have suggested that in highly vulnerable populations, the possibility of an outbreak may exist at concentrations varying from 10–30 oocysts per 100 mL of finished water. From Table I, it can be seen that this potentially infective dose for susceptible individuals was reached on only two days; day 7 when 28.12 oocysts per 100 mL, and on day 11 when 25 oocysts per 100 mL were detected. These observations strongly indicate that the Manz intermittent slow sand filter is an extremely efficient system for removing parasitic cysts and potential health hazards from water intended for human consumption.

Maximum metolachlor levels in Canadian river, well, pond, and rain waters are in the 10 ppb range (Hall et al., 1993; Frank et al., 1990) while the detection limit for metolachlor by *Daphnia magna* varies from 2–5.6 ppm depending on water pH, hardness and trophic status (Dutka et al., 1995). In this study, the Lake Ontario input waters were spiked with 50 ppb metolachlor or $5 \times$ the highest natural occurrence. However three replicate immunoassays on the spiked input wa-

TABLE I. Investigation of the Manz intermittent slow sand filter to remove cryptosporidium and giardia from water

Days after Inoculation	Cryptosporidium Oocysts Recovered per Liter	Giardia Lamblia Cysts Recovered per Liter	Liters Filtered
1	0	0	16
4	0	0	16
5	0	0	16
6	40	0	16
7	281.25	0	16
8	17.5	0	16
11	250	0	16
12	0	0	16
13	50	0	16
14	87.5	0	16
15	25	0	16
18	0	0	16
19	0	0	16
20	26.3	0	16
21	21.9	0	16
22	25	0	16
25	0	0	15
26	0	0	16
27	0	0	12
28	0	0	16
29	0	0	20
Total liters filtered			335
Total oocysts recovered	13,191	0	
Obocysts per liter	39.37	0	
Percent retained	99.986	100	
Original inoculation	1,000,000	100,000	

ters gave readings of 25.92, 25.02, and 25.66 ppb metolachlor. These values we believe are the actual concentrations resulting from our spiking.

Hamilton harbor waters which are badly contaminated with polyaromatic hydrocarbons (PAHs) (International Joint Commission, 1985) have levels varying from 20–118 ppt of which 20% of this concentration could be due to phenanthrene (Fox et al., 1996, Fox, personal communication).

Sixteen liters of input waters were spiked with 750 μg phenanthrene or over $10 \times$ the levels found in environmental waters. None of the bioassays used in this study were able to detect an impact from the 750 μg phenanthrene addition.

These concentrations were selected as they were within the immunoassay test kit ranges and we had unrealistically thought that we may observe synergistic reactions without having to increase the toxicant levels to far above reality and solubility ranges. However during the course of the metolachlor and phenanthrene additions, a total of 500 μg or 0.5 ppm metolachlor and 7500 μg or 7.5 ppm of phenanthrene were added to the sand filter. Thirteen days after the last chemical addition all the filtered water bioassays were still negative

suggesting that there was no massive breakthrough of chemicals.

Cumulative percent retention of metolachlor by the MISSF is shown in Table II. Cumulative percent retention was calculated using the following relations;

$$R_n = \frac{\Delta S}{\sum_{i=1}^n C_{Ii} V_{Ii}} \times 100, \quad (1)$$

$$\Delta S_n = \sum_{i=1}^n C_{Ii} V_{Ii} - \sum_{i=1}^n C_{oi} V_{oi}, \quad (2)$$

where: R_n is the cumulative percent retention of metolachlor on day n , n is the number of days since the beginning of test, ΔS_n is the change in the amount of metolachlor from the beginning of the study, C_{Ii} is the concentration of metolachlor in the water added to the filter on day i based on immunoassay data, V_{Ii} is the volume of water added to the filter on day i , C_{oi} is the concentration of metolachlor in the water which leaves the filter on day i based on immunoassay data, V_{oi} is the volume of water which leaves the filter on day i , ($V_{Ii} = V_{oi}$).

TABLE II. Metolachlor^a retention in the Manz intermittent slow sand filter

Sample #	Day of Test	Concentration Added, ppb	Percent Retention
1	1	27.27	89.6
2	4	27.06	50.43
3	5	25.34	67.93
4	6	22.45	80.08
5	7	22.56	74.79
6	8	25.09	78.88
7	11	25.47	71.78
8	13	22.73	85.5
9	19	21.34	89.4
10	22	0.09	90.57
11	27	0.55	97.63
12	33	0.08	99.02
13	40	0.09	99.7
14	50	0.09	99.84

^a Metolachlor*—0.09 ppb Lake background levels.

Based on immunoassay data, on day 22 there were 83.2 μg of metolachlor within the filter and after 16 L of lake water were added 90.57% of the metolachlor remained. Similar calculations were used to obtain percent retention of metolachlor to day 50 (99.84).

Lake water metolachlor levels varied from 0.55 to 0.05 ppb with the majority of values being between 0.19 and 0.09 ppb (concentrations at the extreme end of the immunoassay's sensitivity range and are believed to be background noise). On day 50 the output waters contained 0.18 ppb metolachlor, very similar to the 0.19 ppb of the lake water added to the filter on day 1. From these data it appears that the MISSF is able to retain from 50 to 99% of a metolachlor concentration that is at least 2.5–8 \times higher than the highest reported concentration in Canadian waters. If we assume that immunoassay values below 0.20 ppb are background noise levels then from day 33 to day 50 there would have been 100% retention of the remaining metolachlor. The lowest retention was after a 3 day period without water addition early in the development of the smutzdecke, and as this biofilm developed the retention of metolachlor or its biodegradation increased, thus resulting in output waters with lower and lower concentrations of metolachlor.

Immunoassay data indicated that there were no detectable levels of phenanthrene in the unspiked input lake waters. The most likely reason for this is the immunoassay kit sensitivity level is 5 ppb and the highest reported level for phenanthrene within the Lakes Ontario and Erie basins is 77 ppt (Michor et al., 1996). Thus all the unspiked input lake waters had phenanthrene levels of < 5 ppb. Although the input lake waters were spiked with phenanthrene to achieve

a level of approximately 47 ppb, when these spiked waters were tested for phenanthrene–PAH levels the concentrations found varied from 10.6 to 66 ppb. Listed in order are the nine input phenanthrene concentrations (ppb) as provided by the immunoassay kit: 12.2, 14, 43, 10.6, 22.3, 66, 21, 42, and 52. All filtered water samples during this 50 day study indicated the presence of < 5 ppb phenanthrene. Thus under the worst case scenerio there was only a 53% retention/removal of phenanthrene to at least 92.5% removal–retention of the PAH phenanthrene which was added in amounts at least 10 \times the highest recorded level in Canadian waters.

In earlier studies we had found *Daphnia magna* EC₅₀ values for Hg and nonylphenol to be 0.1 and 0.5 ppm and EC₅₀ 15 min and microtox values to be 0.046 and 1.35 ppm. The addition of 5 ppm Hg and 10 ppm nonylphenol to Bow River water and then putting it through the MISSF produced a variety of bioassay responses shown in Table III. Here it can be seen that the Microtox bioassays over 16 days produced very similar results. None of the filtered water samples were sufficiently toxic to produce a response in the Microtox system. From the Microtox assays it can be surmised that there was, conservatively, at least 75–80% more toxicant in the input water as compared to the filtered water. Or conversely, based on the Microtox assay the MISSF produced at least a 75% reduction in toxicity. The *Daphnia magna* results were more variable. Toxicity reduction as measured by *Daphnia magna* responses

TABLE III. Mercury and nonylphenol toxicity removal from Bow River water by the Manz intermittent slow sand filter

Day of Sample Processing	Daphnia Magna % Sample = EC50	Microtox % Sample = EC50
1 input ^a	EC10 ^b	> 100
output	100	> 100
4 input ^c	0.7	24.9
output	90	> 100
6 input	0.6	22
output	0.7	> 100
11 input	2	23.4
output	5	> 100
16 input	0.1	20.1
output	3	> 100
31 input	6	NT ^d
output	25	NT
Bow River	Neg	NT

^a Input/output = Bow River with no additions.

^b EC10 = only 10% of animals died.

^c Input = 5 ppm Hg + 10 ppm nonylphenol in 25 L Bow River water.

^d NT = not tested, lab error.

in the filtered water were shown to vary from a low of 50% (day 6) to 250% (day 11) and more than a 1000% (days 4 and 16). Based on metolachlor data (filter #1) and *Daphnia* data (filter #2) the MISSF removes at least 50% of toxicants (some of the pesticides have genotoxicity activities) added at concentrations at least $10\times$ the concentrations found in polluted environments. We suspect that the MISSF under normal working conditions could remove greater than 50% of organic and inorganic toxicants, at normal environmental concentrations, from waters used as potable water source water. This we believe can be easily proven (but costly) by detailed chemical analyses of input waters and filtered waters at ppb and ppt levels.

Approximately 4 weeks after the above study with filter #1 another minor study was initiated to confirm our belief that under "normal working conditions" the MISSF could remove at least 50% of a waterborne toxicant. To partially explore this potential we spiked Lake Ontario waters with HgCl_2 to achieve concentrations in the 150 ppb Hg range. Over a 9 day period 40 L of spiked lake water were added daily to the filter. During this period both input ($6\times$) and filtered water ($9\times$) were monitored for Hg concentrations, with the filtered water being sampled after 39 L of water had passed through the filter. After the last addition of HgCl_2 spiked lake water, 40 L of lake water were added daily for 5 days with input and filtered waters being tested daily for Hg concentrations. It was during this latter phase of the study that it was again confirmed that the lake water used had Hg concentrations below the method detection limit (0.125 ppb) as defined for the Province of Ontario MISA program.

The efficiency of the filter to remove–retain Hg from the spiked lake waters are shown in Table IV. From these data it can be calculated that the mean Hg input concentration was 161.7 ppb and the mean Hg concentration of the filtered water was 7.63 ppb. Thus during this period there was $>92\%$ retention of Hg within the filter. Over the next 5 days when no detectable levels (<0.125 ppb, based on the sensitivity of the procedures used) of Hg were added to the filter, the 40 L of filtered water per day had a mean Hg concentration of 18.04 ppb, indicating a $>86\%$ retention of the original Hg load in the filter at the end of this period. On days 20 and 21 the mean Hg concentration in the outlet waters was 1.8 ppb, a level considered safe for drinking waters (Nikiforuk, 1996).

Seven days after the completion of the above study we tested the MISSF's ability to impact on some basic physical, and biochemical parameters; TSS, TOC, COD, and BOD over a 3 day period during which 40 L of Lake Ontario water were put through the filter daily. The results are shown in Table V. The most striking feature of these data are that COD tended to increase

TABLE IV. Efficiency of the Manz intermittent slow sand filter to remove Hg from lake water spiked 100–200 \times normal environmental levels

Day Sample Collected	Inlet Hg ppb	Filtered Water Hg ppb
1	98.9	12.9
2	152.5	12.0
3	149.5	14.0
4		15.3
5	198.0	8.87
6		10.6
7	208.0	15.0
8		8.01
9	163.3	14.5
10	<0.125	18.2
11	<0.125	18.03
12	<0.125	18.5
13	<0.125	20.9
14	<0.125	14.6
20	<0.05	2.02
21	<0.05	1.57

as it passes through the filter. Also the MISSF appears to show increasing efficiency, with time, to retain–bio-degrade ($11->100\%$) the other parameters. Perhaps these data are indicative of a period of stress that the Hg additions may have put on the smutzdecke. The implications of these data, or whether these data are typical for all operating periods of the filter are not known. A longer study using different degrees of polluted water could possibly clarify our observations.

The next day after the above tests were completed, the integrity of the smutzdecke and the sand filter were destroyed in order to collect samples for toxicity testing by the sediment-chromotest solid phase bioassay. However, prior to collecting the smutzdecke–sediment samples we noted that the smutzdecke was not complete and looked very similar to the initial viewing of the smutzdecke after 16 days of lake water feeding. It was then realized that there had been leakage of water from around the filter screen and this turbulence was responsible for the loss of 10–15% of the smutzdecke. This break in the smutzdecke may have been partially responsible for some of the HgCl_2 which passed through the filter. Samples were collected from the top cm #1, (smutzdecke and sand), from #2 the 2.5 cm level, the 10 cm level, #3 and the 27 cm level, #4. When these solid phase samples were tested, the following results were noted; #1, 12.5% of the sample produced an EC_{100} effect, #2, 25% of the sample produced an EC_{100} effect, and samples #3 and #4 were completely negative for toxic effects at the highest concentration tested, 50%.

TABLE V. Study of the impact of the Manz intermittent slow sand filter on some physical and biochemical parameters on Lake Ontario water

	Day 1		Day 2		Day 3	
	Input	Filtered	Input	Filtered	Input	Filtered
TSS mg/L	2.60	N.D. ^a	5.0	N.D. ^a	9.0	N.D. ^a
TOC mg/L	2.77	2.38	2.25	1.84	2.07	1.69
COD mg/L	23	24	21	21	14	22
Total BOD 5	3.65	N.D. ^a	3.05	N.D. ^a	5.6	N.D. ^a

^a N.D. = not detected.

These results tend to support the belief that the smutzdecke plays a major role in microorganism, parasite, and toxicant removal, either by retention, (as indicated by the above toxicity study) biodegradation or biotransformation (metolachlor and phenanthrene study), or combinations of these actions (microorganism and parasites). Perhaps, over time, an excess bioaccumulation of toxicants in the smutzdecke may sporadically decrease its activity and may be the reason for some of the aberrant results we have occasionally noted.

CONCLUSIONS

1. Even without the development of a complete biofilm (smutzdecke) the Manz intermittent slow sand filter (MISSF) was able to remove approximately 83% of the total heterotrophic bacterial population from input waters.
2. The MISSF when challenged with massive concentrations of parasitic cysts was able to retain 99.98–100% of the cysts with no breakthroughs 22 days after massive inoculations.
3. The MISSF when challenged with organic and inorganic toxicants at levels of 10–100 × normal environmental levels was found to be able to retain between 50–99% of toxicants. It would appear that many of the toxicants are entrapped, biodegraded, or biotransformed in the smutzdecke as shown by increased toxicant levels over time in the smutzdecke.
4. The development of a good biofilm is essential for maximum efficiency of the MISSF. The more biologically productive the waters used to develop the filter biofilm, the quicker and more efficiently the filter operates.
5. It is believed that the height of the standing water may be important in the development of the biofilm; 2–3 cm appears to be an efficient level.
6. The MISSF is much more than a bacteriological filter, it possibly has a greater impact in parasitic

cyst removal and decreasing toxicant–genotoxicant concentrations from drinking waters in developing and developed countries.

7. In areas where it is suspected or known that the waters which the people drink contain hazardous compounds and the MISSF is used, it may be prudent to remove the surface biofilm (top 1–2 cm) every 3 or 4 months.

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REFERENCES

- APHA. Standard Methods for the Examination of Water and Wastewater; 19th ed.; American Public Health Association, 1995.
- Aldom, J. E.; Chagla, A. H. *Lett Appl Microbiology* 1995, 20, 186–187.
- Bellamy, W. D.; Silverman, G. P.; Hendricks, D. W.; Logsdon, G. S. *AWWA J* 1985, 77, 2–52.
- Buzunis, B. J. Laboratory Report: Confirmation Testing of an Intermittently Operated Slow Sand Filter; Dept. of Civil Engineering, University of Calgary, 1993.
- Castillo, G. IDRC Project: Water Quality Control (Brazil-Chile) Phase 11; Mid-Term Technical Report CF:3-P-90-0100; International Research Development Centre: Ottawa, ON, Canada, 1992; K1G 3H9.
- Castillo, G.; Etcheberrigaray, E. IDRC Project, CF 92-1058: Community-Based Water Quality Testing; Final Report May 1996; International Research Development Centre: Ottawa, ON, Canada, 1996; K1G 3H9.
- Davnor Water Treatment Technologies Ltd. Installation Instructions for the Canadian Water Filter; Davnor: Calgary, AL Canada, 1996.
- Dutka, B. J. Ed. *Methods for Microbiological and Toxicological Analysis of Waters, Wastewaters and Sediments*; Rivers Research Branch, NWRI, CCIW: Burlington, ON Canada, 1989; L7R 4A6.

- Dutka, B. J.; El-Shaarawi, A. Use of Simple Inexpensive Microbiological Water Quality Tests: Results of a Three Continent, Eight Country Research Project; IDRC Report IDRC-MR247e, Jan. 1990. IDRC: Ottawa, ON Canada, 1990, K1G 3H9.
- Dutka, B. J.; Seidl, P.; Spence, V. Report on the 1990 IDRC Funded Study to Develop a Self-Sufficient Microbiological Water Quality Testing Capability within the Cree Nation of Split Lake; NWRI Contribution 90-170: National Water Research Institute: Burlington, ON Canada, 1990; L7R 4A6.
- Dutka, B. J.; Seidl, P. Procedures for Microbiological Testing of Drinking and Recreational Waters in Remote and Isolated Communities; NWRI Contribution 93-129. National Water Research Institute: Burlington, ON Canada, 1993a; L7R 4A6.
- Dutka, B. J.; Seidl, P. Procedimientos para el examen microbiológico de agua potable y recreacional en comunidades en áreas remotas y aisladas. Available from International Development Research Centre: Ottawa, ON Canada, 1993b; K1G 3H9.
- Dutka, B. J. Water and Sediment Ecotoxicology Studies in Mapuche Homelands and Southern Chile; IDRC Community-Based Water Quality Testing Contract Report No. 92-1058-02; International Development Research Centre: Ottawa, ON Canada, 1995; K1G 3H9.
- Dutka, B. J.; McInnis, R.; Pacepavivius, G. J.; Maguire, R. J. Acute and Chronic Toxicity of the Herbicide Metolachlor to the Water Flea *Daphnia Magna* and the Soil Nematode *Panagrellus Redivivus*; NWRI Contribution No. 95-56; National Water Research Institute: Burlington, ON Canada, 1995; L7R 4A6.
- Fox, M. E.; Khan, R. M.; Thiessen, P. A. Water Quality Res J Canada 1996, 31, in press.
- Frank, R.; Braun, H. E.; Ripley, B. D.; Clegg, B. S. Bull Environ Contamin Toxicol 1990, 44, 401-409.
- Hall, J. C.; Van Deynze, T. D.; Struger, J.; Chan, C. H. J Environ Sci Health 1993, B28, 577-598.
- Haas, C. N.; Rose, J. B. J Amer Water Works Assoc 1995, 87, 81-87.
- International Joint Commission. 1985 Report on Great Lakes Water Quality; Report of the Great Lakes Water Quality Board, 1985.
- Kindzierski, W. B.; Gabos, S. Water Environ Res 1996, 68, 818-826.
- Kwan, K. K. Environ Toxicol and Water Quality 1993, 8, 223-230.
- Lee, D. Development of a Prototype of an Individual Slow Sand Filter for Intermittent Use in the Philippines; Report completed for an undergraduate course, Dept. of Civil Engineering, University of Calgary: AB, Canada, 1991.
- Manz, D. H.; Buzinus, B. J.; Morales, C. Final Report on the Nicaragua household water supply and testing project; Division of International Development, University of Calgary: AB, Canada, 1993.
- Manz, D. H.; Buzinus, B. J. Nicaragua Community Scale Household Filter Project; University of Calgary, Dept. of Civil Engineering: Calgary, AB, Canada, 1995.
- Metcalf, R. L. J Agric Chem 1973, 21, 511-519.
- Michor, G.; Carron, J.; Bruce, S.; Cancilla, D. A. J Chromatography 1996, 732, 85-99.
- Nikiforuk, A. The Amazon and the Canadian Mercury Sleuths; The Globe and Mail: Toronto, Canada, Nov. 16, 1996; p. D6.
- Schuler, P. F.; Ghosh, M. M. Proceedings of the American Water Works Association Annual Conference, Water Quality for the New Decade, Philadelphia, PA, June 23-27, 1991.
- Seidl, P.; Dutka, B. J.; Spence, V.; Webster, R. Self-Administered Bacteriological Assessment Program in Split Lake, Manitoba Ecological Report Series, Northern Flood Agreement Manitoba, Environment Canada, Fisheries and Oceans, No. 90-2, 1990.
- Seidl, P.; Dutka, B. J. Developing a Self-Sustained Microbiological Water Quality Testing Capability within a Remote Aboriginal Community; NWRI Contribution No. 93-124; National Water Research Institute: Burlington, ON Canada, 1993.
- USEPA. Automated Cold Vapor Technique for Mercury. Method 245.2. Doc. 600-4-79-020. United States Environmental Protection Agency, 1974.
- Wells, P. Risk Assessment for Waterborne Giardiasis and Cryptosporidiosis in Canada; Hyperion Research Ltd.: Medicine Hat, AB, Canada, 1995.
- World Health Organization. Global Strategy for Health for All by the Year 2000; WHO: Geneva, Switzerland, 1981.
- Wust, S.; Hock, B. Anal Lett 1992, 25, 1025-1037.