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Slow Sand Filtration at 100 Mile House, British Columbia, Canada

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ABSTRACT

The SSF refers to the treatment of domestic water through a granular filter bed at rate less than 0.4 m/hr. It is a passive process, highly efficient under a number of ambient and operating conditions and requires little operator attention. Particle removal is at the filter surface in a layer termed the schmutzedecke. Headloss is recovered by physically removing this layer.

In response to waterborne giardiasis outbreaks a slow sand filtration plant was constructed in 1984/85 at 100 Mile House, British Columbia. A detailed monitoring program for the year following plant startup on November 15, 1985 found the filters were highly efficient in removing virtually all ambient particulates. The filter cycles were influenced by algal levels in the raw water. The operating cost was about \$0.24 (Can)/10 m^3.

INTRODUCTION

The slow sand filter (SSF) in the context of the treatment of domestic drinking water refers to the gravity movement of water through a granular filter bed at rate less than 0.40 m/h (Huisman and Wood, 1974). The 0.6 to 1.2 m thick unstratified granular filter media, supported by a gravel layer up to 0.6 m in thickness, has an effective size (d_{10}) of 0.15 to 0.35 mm and a uniformity coefficient of 1.50 to 2.50. The media is contained by a filter box having sufficient height to permit about 1.0 to 2.0 m of headwater above the media surface. Drain tiles are located in the gravel layer to collect the filtered water.

Particulate removal is achieved by physical/biological processes in the filter media and to a lesser extent physical processes in the headwater. In the latter case the low filtration rate results in several hours of storage time in the headwater during which flocculation and sedimentation to the filter surface occur. In the former case the particulates in the water passing through the

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media are brought in contact with the media, attach to the media and are either degraded to simpler compounds or physically removed during filter cleaning. As the media is a fine unstratified sand most particulates are removed at the filter surface in a layer termed the schmutzdecke. The schmutzdecke is the location on the sand filter where bacteria and microorganisms multiply using the deposited organic matter as an energy source for their metabolism and growth. As the bacterial population is dependent on the food source available the bacterial growth is accompanied by an equivalent bacterial die-off which provides a simpler organic food source to lower depths in the sand filter.

Microorganism and bacterial activity is most pronounced in the upper part of the slow sand filter and gradually decreases with filter depth as food levels decrease. As their food source decreases they starve, particularly at a high metabolic rate during warm water temperatures. Also, with depth there is a segregation of bacterial types with true water bacteria predominating at lower depths.

The oxidation of the organic matter is influenced by the oxygen level, the amount of organic matter in the raw water and the water temperature. The slow sand filtration efficiency may be reduced at lower temperatures as the rate of metabolism of bacteria and other microorganisms such as bacteria consuming protozoa and nematodes decrease.

With continuous operation the schmutzdecke layer gradually increases in thickness reducing the rate of flow through the filter. At a limiting head loss the headwater is drained to below the media surface and the schmutzdecke and a thin layer of filter media, usually 5 to 10 mm, is physically removed generally by rake and shovel but possibly by mechanical means. Due to the labour intensive nature of the filter cleaning process, filter cycle lengths greater than several weeks are necessary. The filter cycle length is determined by the solids loading to the filter and the hydraulic loading rate. After repeated scrapings the depth of the filter media is reduced and new media must be added to restore the original depth.

HISTORY

The first slow sand filter for public water supply was installed by the Chelsea Water Company in London, England in 1829, based on work at Paisley, Scotland dating from 1804 (Huisman and Wood, 1974). The first installation in the United States was in 1870 at Poughkeepsie, New York. Use continued in England and Europe but was eclipsed in North America by the turn of the century with the new rapid sand technology. The latter was favoured where raw water turbidities were high as slow sand installations in such situations were found to have filter runs of only one or two days, which was not acceptable.

A recent survey (Regli, 1987) of community water systems in the United States found that between one and two percent of communities filtering surface water employ slow sand filtration. The majority of installations are serving communities with population less than 50,000 persons and not being employed in communities where the population was greater than 500,000 persons. In a survey (Slezak, 1984) of 27 operating slow sand filter plants in the United States, 26 percent had been in operation between 75 and 100 years, 30 percent between 50 and 75 years, 11 percent between 25 and 50 years and 33 percent between 0 and 25 years. The average raw water turbidity for the plants was less than 10 NTU with the raw water source typically being a lake or reservoir. The removal efficiency of turbidity and coliform through the filters was reported to be good.

Typical of many European water treatment plants employing slow sand filtration is the Weesperkarspel plant treating water for Amsterdam (Van der Veen 1985). The unit processes in order of operation are ozonation, addition of powdered activated carbon, coagulating rapid sand filtration, slow sand filtration and chlorination.

TREATMENT EFFICIENCY

The SSF is a highly efficiency filtration process under a number of ambient and operating conditions.

An evaluation of the effectiveness of slow sand filters and the role of operating conditions on the removal of the Giardia cyst were investigated at Colorado State University under a cooperative agreement with the United States Environmental Protection Agency (Bellamy 1985). The research looked at the effects on cyst removal of hydraulic loading rate, temperature, cyst concentration, age of schmutzdecke, and age of filter bed (biological maturity). The hydraulic loading rates included 0.04, 0.12 and 0.40 m/hr, the raw water cyst concentrations ranged from 50 to 5,075 cysts/litre, and the raw water temperatures were 15° and 5°C. Conclusions were that the cyst removal can be expected to be greater than 98 percent when the filter is establishing the biopopulation within the sand bed and is virtually complete once established. Within the limitations of the research, temperature, cyst concentration and hydraulic loading rate did not affect cyst removal. The most important variable in the performance of the filter media was established to be the biopopulation within the sand bed. Absorption and then metabolism, by microbial films on the sand grains constitute a major removal mechanism. Pilot plant work demonstrated 99.9 percent removals of coliform bacterial spikes and 85 percent coliform removal even with new sand. Turbidity reduction of 27 to 39 percent was noted.

Logsdon (1983) reported coliform removal of 99 percent for the months of March to November and 94 percent to 97 percent for the months of November to January at a full-scale slow sand filter. The cyst removal was 99.9 percent at a variety of operating conditions but the author noted that at low temperatures the Giardia cyst removal efficiency may decrease.

The United States Public Health Service reported virus removals of 22 to 96 percent and the Metropolitan Board of Health in London, England, found reduction of 99.9 percent in viruses through a laboratory size slow sand filter at temperature 11-12°C and 99.8 percent with temperature at 6°C. (Logsdon, 1982).

Excellent removal of reovirus (McConnell, 1984) was demonstrated through slow sand filtration even at filter startup in the absence of filter maturation. E. coli removal was 99.97 percent or greater at an average loading of 7.5×10^7 E. coli per pilot filter but when the loading was increased by 3 logs units breakthrough occurred. Biological activity was present through the entire filter depth.

The reported slow sand filtration ripening period varies from 2 days (Cleasby, 1984) in a pilot filter to 6 hr to 2 weeks (Letterman, 1985) in 6 operating slow sand filter plants. In the latter case the ripening stage as identified by a reduction in turbidity removal and an increase in the particle count with the length of the ripening period not related to prechlorination, water temperature, scraping method or frequency of filter maintenance.

FILTER CYCLE

A high quality water source to the slow sand filter is required as the filter cycle between filter scraping is of fundamental importance. If the cycle is too short the labour costs associated with cleaning will be high and the filters will be out of service for too great a proportion of time. The filter cycle is variable and related to raw water quality parameters such as algal population (Cleasby, 1984) solids loading as measured by turbidity (Slezak, 1984) and iron level (Letterman, 1985). In a survey (Slezak, 1984) of 21 slow sand filter plants in the United States the longest filter cycles were in the winter season, typically 60 days, although winter/summer cycles were longer than spring/fall cycles in several instances. The mean cycle length in the summer season was 43 days. In a survey (Letterman, 1985) of six slow sand filters in the United States the average filter run production was between 121.4 m^3/m^2 to 640.5 m^3/m^2 with the average frequency varying between 1.8 to 12 scrapings per year. The length of the filter cycle (McNair, 1987) was increased when the filamentous algae was present in the schmutzdecke rather than when the small algae such as diatoms predominate.

COST

The SSF is passive in nature and requires little operator attention. The typical operations costs relate to labour for filter scraping, labour for resanding and daily inspection. In the survey (Letterman, 1985) of 6 slow sand filters in the United States the time required to scrape a filter varied between 2 and 23 to 42 manhours per 100 m^2 , to resand a filter 218 to 618 manhours/year and 365 manhours/year for daily inspection. The total operation and maintenance cost varied between \$0.01 (US) to \$0.11 (US)/10 m^3 while another survey (Slezak, 1984) found the cost to be less than \$0.26 (US)/10 m^3.

100 MILE HOUSE, BRITISH COLUMBIA, CANADA

Background

In 1981, 1982 and 1983 at least 60, 50 and 30 confirmed cases of Giardiasis associated with Giardia lamblia were confirmed at 100 Mile House, population 2000 persons. The outbreak affected people living in a wide geographical area around 100 Mile and no other source explained the findings as well as waterborne contamination of the municipal water system. The source was suspected to be beavers and muskrats subsequently confirmed positive for Giardia cysts and located upstream of the Village's surface water intake. The water supply was surface water from Bridge Creek. The addition of chlorine solution, with minimal contact time provided in the distribution system was the only treatment practised. The water quality in Bridge Creek generally met the maximum levels recommended for domestic consumption (Canadian Water Quality Guidelines, 1987) including turbidity levels of less than 2 NTU year around. In periods of low flow, especially in the summer, the total coliform levels exceeded the water quality standards.

The occurrence of the giardiasis outbreak instigated a comprehensive re-examination of the water supply situation at 100 Mile House. The further development of the Bridge Creek surface water source, including a treatment plant incorporating filtration, was chosen by Village Council as the preferred method of meeting the Villlage's water demand. The major concern with design of the treatment plant for a small community such as 100 Mile House, population 2000 persons, was to choose a filtration process that reliably ensured protection against the passage of the cyst from the low temperature, low turbidity water source to the distribution system and yet minimize the yearly operation and maintenance cost. The fact that even without filtration the water source met the current drinking water objectives, except for the implied presence of the giardia cyst, allowed a number of filtration processes to be considered.

Between June and October 1983 a pilot plant study was conducted. Four types of filters were used in the program including gravity rapid rate multi-media filtration, pressurized rapid rate muti-media filtration, slow sand filtration and diatomaceous earth filtration. Based on the pilot plant results, capital and operation and maintenance costs were estimated for full scale plants and an evaluation was made of each treatment method. The pilot plant study showed that all processes were effective and would have about the same capital costs. Based upon the pilot plant results, coupled with a judgement factor to account for operation aspects appropriate for 100 Mile House, slow sand filtration was recommended by the consulting engineers and selected by the Village Council as the method of filtration.

Water Treatment Plant

The Village's water treatment plant constructed in 1984/85 includes a surface water intake, raw water pump station, three cast-in-place concrete slow sand filters, chlorinating equiment and contact tank, a clearwell, treated water pumps and a control building. A design summary is presented on Table 1.

The filters are covered using precast reinforced concrete slabs to reduce algae growth and to minimize ice formation since ambient air temperatures in winter can range from -20 to -40°C for two to four weeks. The manual operation of each filter is controlled by a butterfly valve adjusted each day to the anticipated Village demand. To avoid a negative pressure in the media the water from each filter passes over a weir. A set of two piezometers, one in the filter headwater and one in the filter underdrain, are used to measure the filter headloss. The total construction cost for the new water treatment system was $780,000 (Can).

Evaluation

The plant was put into production November 15, 1985. An evaluation (Bryck, 1987) of the first year of operation of the slow sand filtration plant from November 15, 1985 to November 15, 1986 was made. The evaluation included the determination of removal efficiencies of various particles, measurement of headloss increase with time and scraping frequency, an assessment of biomass activity within the sand bed, and an enumeration of operation and maintenance costs.

Table 1: Design Summary

Design Population		4,300
Flow	Peak Production (all 3 filters operating)	84 L/S; 7.26 mL/d
	Diameter:	300 mm diameter slotted SDR 26 PVC
Filters	Hydraulic Rate	$0.19\ m^3/m^{\cancel{3}\,2}/h$
	Number of Filters:	3
	Filter Surface Area:	$258\ m^2$/filter
	Filter Length:	43 m
	Filter Width:	6 m
	Nominal Depth,	3.8 m
	Capacity through each Filter at Hydraulic Rate:	1.2 mL/d
	Underdrains:	150 mm diameter slotted SDR 26 PVC pipe
	Operation Head above Outlet Weir:	1.80 m
Sand media	Depth at startup:	1,050 mm
	Effective Size:	.20 to .30 mm
	Coefficient of Uniformity:	3.30 to 3.80
Support Gravel	Gravel 1:	D10 = 3.0 mm D 90 = 6.0 mm
	Gravel 2:	D10 = 8.8 mm D90 = 14.0 mm
	Gravel 3:	D10 = 20.0 mm D90 = 63.0 mm
Rate of Flow Controller	Type:	Manually Operated Butterfly Valve
Chlorine Contact Tank	Volume:	$50\ m^3$
	Detention Time at Peak Day Flow:	20 min.

Village Demand

The average annual daily village water demand was 1.496 mL/d, the average daily demand in the peak month was 2.300 mL/d while the average daily demand in the peak week was 2.680 mL/d and the peak day demand was 3.500 mL/d. For the peak day and all filters operating the unit hydraulic rate was $0.19\ m^3/m^2$/hr.

Particle Removal Efficiency

Removals of a wide range of particles were measured for the full-scale filters. Twenty-one raw water cartridge samples were compared with 22 filtered water cartridge samples with respect to *Giardia* cysts and microscopic particles. *Giardia* cysts were detected in 11 of the 21 raw water samples, with counts as high as 300 cysts. Zero cysts were detected in every sample of the filtered water. These results are consistent with similar sampling of a slow sand filter at Empire, Colorado where cysts were detected in 5 of 11 raw water samples and zero cysts were detected in every effluent sample (Seelaus, 1986). Other particles retained on the cartridge filters and counted in terms of relative estimates included parasitic nematode eggs, coccidia, plant debris, free-living nematodes/eggs, fine and large amorphous debris, flagellates, sediment, diatoms, pollen/ciliates and occasional crustaceans/eggs. In almost every case where significant relative counts, measured as to~(occasional) to ++++ (extremely heavy), were obtained in the raw water, they were mostly 0 to~in the finished water. This included heavy to extremely heavy algae amounts in July and August in the raw water and 0 to occasional algae in the filtered water. The evidence is abundant that the filter was highly efficient in removing virtually all of the ambient levels of particulates which challenged it. This conclusion was confirmed further by colour comparisons of the raw water/filtered water cartridge filters. In every case the raw water cartridges were brown to dark brown while the filtered water cartridges were white to off-white, with a few tan ones. The turbidity in the raw water varied between .15 NTU and 3.5 NTU. Turbidity removals were about 50 percent, with effluent turbidities reflecting the changes in raw water turbidities, and were less than 0.6 NTU more than 80 percent of the time.

Biomass Activity

Media samples were taken prior to filter scraping in March, June and August at filter media depths of 0 to 7 mm, 300 mm, and 600 mm.

Table 3 provides a summary of the number of invertebrates and number of taxa within each sample.

Table 3: Summary of Invertebrates in Sand Media

	Total Number of Specimens			Total Number of Taxa		
Depth (mm)	March	June	August	March	June	August
1-7	13	61	2264	2	8	6
300	-	2	852	-	2	5
600	-	0	337	-	0	2
Schmutzdecke Age (days)	137	214	85	137	214	85

The taxa, or groupings of invertebrates, were identified as the level of order and family and each taxon may represent a variety of different genera and species. Counts of invertebrates within the sand filter demonstrated an increasing trend from March to August at all depths, with the majority of the organisms also being located in the top layer. In March, organisms were found only in the top layer. The numbers were few, and they were likely entrapped from the incoming water. Overtime, colonization by organisms more suited to the environment became established; in June the taxa Chironomidae (midge fly) predominated while in August the taxa Oligochaeta (worm) was dominant. Oligochaetes are true aquatic animals which feed on bacteria, and their increasing presence reflects the maturation of the biological ecosystem within the filter with the development of indigenous species.

The activity of the heterotrophic bacteria with depth was assessed using a modified resazurin reduction technique to measure microbial dehydrogenase enzymes. This technique distinguishes between the viable and non-viable cells. The more common direct cell count technique is unable to do this. The results are summarized on Table 4.

Table 4: Heterotrophic Bacterial Activity

	Rate of Resazurin Reduction (umole/g/hour)		
Depth (mm)	March	June	August
1-7	0	0.32	0.060
300	-	0.12	0.016
600	-	0	0.016
Schmutzdecke Age (day)	137	214	85

The highest levels of bacterial activity were at the filter surface or the schmutzdecke. The June and August were taken just prior to scraping. Bacterial level was low in the March sample probably due to the continuous low raw water temperature of 1° to 3°C since filter startup in November 1985. However, bacterial activity increased in the June and August samples likely reflecting a higher water temperature and more favourable climate for bacterial activity. It is not known why the bacterial activity was less in August over that of June although the age of Filter 1 was 85 days in August and Filter 3 was 214 days in June.

Filter Cycle

The length of time required for the headloss within a filter cell to reach the terminal headloss of about 1300 mm determined the length of run. A summary of the Filter 3 cycle data, typical for Filters 1 and 2, is presented in Table 2.

The net production between filter scraping varied seasonally with low production in the high algae summer periods (Synedra, Ceratium, Fragilaria, Dinobryon, Asterioella) and high unit production in the low algae winter periods.

Operation Costs

The annual operating costs were $20,700 (CAN) or $4,500 for chlorine, $7,000 for power consumption (raw and treated water pumps), $5,500 for daily inspection, $2,700 for filter scraping, $1,500 for media replacement, $1,000 for equipment maintenance and $1,500 for administration. The plant was inspected every day for 0.5 hr to 1.0 hrs. to complete records of pump operating times, filter flows, treated water demand flow, water quality analysis, chlorine used and headloss data. The scraping steps involved draining to waste the filter headwater, removal of 12 cm of sand surface by raking into windrows and shovelling into wheelbarrows, refilling the bed from filter bottom, and filter to waste. The total time elapsed was 24 hours with less than 4 hours for scraping. The person-hours required for scraping was about 15 for 6 m x 43 m cell, with a cost of \$225/scraping. The unit cost of operation and maintenance was \$0.24 (CAN)/10m^3 on 854,000 m^3 of water produced.

Table 2: Cycle Summary - Filter 3

Cycle Number	1	2	3	4	5	6	7	8
Cycle Start	Nov 85	Jun 86	Jul 86	Oct 86	Dec 86	May 87	Jun 87	Jul 87
Cycle Stop	Jun 86	Jul 86	Sep 86	Dec 86	May 87	Jun 87	Jul 87	Sep 87
Cycle Length (days)	214	50	62	62	154	36	34	50
Net Production (m^3)	201196	51385	73027	50904	99542	35989	36607	45910
Net Production/ Filter Area (m^3/m^2)	779.8	199.2	283.1	197.3	385.8	139.5	141.9	177.9
Average 3 Day Headloss (mm) at 12 L/S:								
a) After Start of Cycle	0.20	0.178	0.215	0.286	0.287	0.279	0.228	0.213
b) Prior to End of Cycle	1.323	0.944	0.801	0.547	1.599	1.578	1.437	1.555
c) Net Headloss	1.126	0.766	0.586	0.261	1.311	1.299	1.208	1.342
Production Per Unit of Headloss (m^3/m^2/mm)	0.692	0.260	0.483	0.756	0.294	0.107	0.117	0.133

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