The ability of a slow sand filter to form the biolayer is related to the low surface loading rate, typically 0.1 to 0.4 $m^3/h/m^2$ in combination with use of clean small diameter filter media (d_{10} between 0.15 and 0.35 mm with uniformity coefficient of 3) and the low operating heads, approximately 1 m. The use of sub-angular media (such as obtained from crushed rock) is thought to improve pathogen removal. It is generally believed that the lower the d_{10} and the uniformity coefficient the better the filter media will perform. It is also required that the media meet American Water Works Associate standards for hardness and purity, AWWA – B -100, a requirement typically achieved by using crushed and washed quartzite or similar materials. It is important that the filter media not have particles made of soft shale or mud stones high in oxidized metals. The AWWA Manual of Design for Slow Sand Filtration, Hendricks ed. (1991) specifies a minimum depth of filter bed, not including the underdrain materials, of between 0.3 to 0.8 meters. TSSF's have used beds of more than 1.0 meter deep to allow several 'cleanings' which each remove up to 5 cm each before a 're-bedding' or 'topping-up' of the filter bed is required. Flow rate through the filter bed is controlled using valves or weirs with adjustable height.

There are concerns regarding effect of temperature on the performance of TSSF's particularly water that is near freezing. Raw water temperature will determine the water viscosity and the colder the water the lower the infiltration rate all other factors being equal but this can be compensated for by increasing available head for filtration. The principle concern is the effect very cold temperatures have on biological processes which should be broken in to organism capture and organism metabolic process. Despite well published experiences indicating failure of TSSF's to remove parasites, Giardia cysts or Cryptosporidium oocysts, from near freezing water it is generally agreed that properly designed and operated TSSF's are effective in removing parasites even when the temperature of the raw water is near freezing Hendricks and Bellamy in Logsdon ed. (1991).

MANZ SLOW SAND FILTER

The Manz Slow Sand Filter (MSSF) adheres to the same design criteria as recommended for TSSF technology and exhibits the same treatment characteristics as TSSF technology. However, the MSSF technology can be demand operated and cleaned using a unique backwash system.

Principles of design, operation and performance

The bed of filter media used in a MSSF consists of at least two layers of crushed quartzite (silica) with effective sizes of 0.15mm and 0.35mm and uniformity coefficients less than 2. The exact thickness of the two materials is a function of the objective surface loading rate and is determined by pilot study. The use of crushed quartzite, rather than rounded particles of quartzite, is preferred as it is reduces the magnitude of backwash flow rates required to fluidize the filter layers at time of commissioning and in subsequent backwash operations. The depth of the filtration layer is 0.5 m or as specified by appropriate regulatory agency. The commissioning process fluidizes both filtering layers and insures that the finest particles (less than 0.15 mm) are at the media surface to provide superior filtration.

The flow of filtered water is controlled using a 'weir-type' outlet system (outlet standpipe) connected directly to the filter underdrain system. This concept is similar to that used with traditional slow sand filters. The use of the outlet standpipe insures that the filter bed cannot be dewatered. The maximum flow from the filter (often specified by regulatory authorities) is established by the design of the media bed and the provision and adjustment of a production control valve when the filter is commissioned. During normal operation the flow of water into the filter and the maximum depth of water over the filter bed are established by mechanical float valves attached to the raw water inlet pipes within the filter itself insuring that the flow of water into the filter cannot exceed its production. The erosive power of the water from the raw water inlet system is eliminated by passing the water from the mechanical float controlled valves into diffuser basins located above the minimum depth of water in the filter. When the treated water storage is full the flow of raw water to the MSSF is stopped and the depth of water in the filter is allowed to drop to a minimum level that allows sufficient oxygen to diffuse to the biolayer to keep it alive and healthy. The rate of filtered water flow, filter bed design and hydraulic head loss across the filter bed ensure that the filter will meet water treatment expectations consistent with that of slow sand filters performing the same treatment function.

The operation of the MSSF technology is similar to that of its precursor the BioSand Water Filter (BSF) technology, formerly known as intermittently operated slow sand filtration or Manz Intermittent Slow Sand Filter. The BSF technology is now only recommended for use at the household level though systems have been constructed to produce more than 100,000 L/h. Good descriptions of the household scale of the BSF technology as used at the household level in more than 100 countries around the world may be found in the web site: www.manzwaterinfo.ca. The BSF technology is considered the best point-of-use technology available for use in developing countries Sobsey et al (2008). The BSF technology had already been extensively evaluated for both bacteria and parasite removal Palmateer et al (1997) where the technology demonstrated 3 and 4 log removals for Cryptosporidium and Giardia respectively as well as 95% removal of bacteria and substantial removal of organic and inorganic toxins. The parasite challenge was onerous in the sense that the filter was administered a 20 L water sample with 1,000,000 Cryptosporidium oocysts and 100,000 Giardia cysts and tested over a 30 day period. The evaluation reported by Palmateer, et al is especially interesting when it is realized that a portion of the filter surface was continually being scoured during routine operations because of an inadequately fitting diffuser basin, a problem that was only identified after the paper had been published. It is certain that the bacteria removal would have been higher, approaching 99%, and the oocyst removal 4 log or better; however, the technology performed as well as the best operating TSSF's. The design of the MSSF allows for demand operation; that is, used as required to fill the treated water reservoir without loss of performance.

Cleaning using backwash

The outlet system is also connected to a filtered water supply that is not chlorinated and can be used for filter backwashing. Once it is determined that filter production is unacceptably low, (perhaps determined by the examination of sight-glasses permitting observation of water depth in the filter and outlet head), filter production is isolated and backwash water is allowed into the underdrain system. An air-vacuum control valve attached to the top of the outlet standpipe ensures that the filter produces treated water with the outlet under atmospheric pressure and backwashes under full backwash pump pressure.

The backwash of a MSSF is only intended to thoroughly break up the upper few centimetres of media (where virtually all of the material is collected), de-gas the media and re-suspend captured material. As mentioned only filtered water, that has not been chlorinated, is used for backwash. The flow rate is equal to the minimum backwash flow recommended for start-up of the backwash process used by rapid sand filters or pressure sand filters, approximately 1 $L/s/m_2$ of filter surface under less than 5 m of head. Backwash of a MSSF may fluidize and flush the entire filtering layer as well but much less aggressively than that used by rapid and pressure sand filters. Wastewater produced by an MSSF is typically less than 1% of filter production.

When the backwash flow is stopped, the fluidized layers in the MSSF collapse into layers resembling the original filter bed (post commissioning). Remaining backwash water is 'squeezed' out and upward from the filter media and the media bed settles cleaned. No untreated water can enter the media bed. The schmutzdeke will be lost during the backwash process. The same fine particles that formed the top of the filter media when the filter was commissioned remain at the top of the media bed after each backwash. These are the same particles that formed biofilms and constitute the biolayer or active layer. The biolayer is in place after every backwash - no matter how frequently the backwash is required. The implication is that filter performance is not temporarily impaired by the backwash process. Removal of pathogens, parasites (Giardia and Cryptosporidium), bacteria and viruses can be expected to be similar to that prior to backwashing, flow rate considerations withstanding. Any problems associated with air binding are eliminated because the backwash process is used. Short-circuiting is not possible.

The wastewater produced during the backwash process is removed, after allowing the finest media to settle (about 30 seconds), using perforated pipes located along and attached to the interior walls of the filter. The holes in the pipe are slightly downward facing to avoid capturing any of the fluidized media and are located approximately five centimetres above the surface of the media (all of the water is not removed). The perforated pipes are attached to a siphon spillway system that also acts as an emergency overflow system. The rate of flow through this system is controlled by a dedicated waste water flow control valve (not greater than the capacity to take the wastewater to disposal). A second, waste water operations valve is used to alternatively prevent flow from the filter until backwash is completed and then opened to facilitate the siphon evacuation process. The same valve is left open after backwash is completed to provide emergency overflow protection.

Should the filter develop significant quantities of large, floating debris (not usually a problem if the filters are covered) it may be necessary to locate troughs slightly above the normal backwash which would allow surface skimming.

The backwash process used to clean the MSSF is expected to allow use of the same filter bed for at least ten years. BSF treatment systems that are cleaned using a surface agitation, reverse flow for degassing and a decant similar to the MSSF have been in operation for more than eight years. Media is never lost and organic material resulting from sloughing of mature biofilms will be removed during the backwash process. It is difficult to identify the circumstances where the filter media used in an MSSF would need to be replaced.

A filter-to-waste procedure can easily be incorporated if necessary. A filter-to-waste provision is always available to accommodate filter commissioning.

It is advisable to divide the entire filtration plant into equal segments (at least two) that can be cleaned independently using lower capacity distribution pumps or backwash water head tanks and produce flow rates and volumes of wastewater that can be economically evacuated and disposed of through existing sanitary sewers if necessary.

MSSF systems are scalable from a few hundred to several million litres per hour.

COMPARISON OF SAND FILTERS

Table 1.0 compares the effectiveness, physical and operational characteristics and costs associated with traditional slow sand filters, rapid sand filters, pressure sand filters and the MSSF.

The following observations can be made:

1. The TSSF and MSSF technologies are very effective in removing pathogens.
2. All types of slow sand filters are very effective at removing inorganic or organic particulate material with or without pre-treatment. The TSSF is limited because of the significant effort required to clean it.
3. The TSSF and MSSF will not exhibit break through phenomena. It is impossible for these filters to produce untreated water. Unlike rapid sand and pressure sand filters, TSSF and MSSF continue to improve their ability to treat water until such time as the captured material completely stops the flow of water through them. The TSSF and MSSF are cleaned when their capacity drops to unacceptably low levels (50% of maximum production is normal).
4. The TSSF and MSSF technologies are all very effective in removing oxidized iron and manganese though the TSSF is not practical because of the significant effort required to clean it.
5. Except for having a relatively larger surface area, the MSSF cells are structurally compact and simple to construct. Their construction costs are very low.
6. The TSSF, RSF and MSSF are all appropriate for use in large scale applications.
7. The PSF and MSSF are particularly appropriate for use in small scale applications.
8. The TSSF produces almost no waste water; the MSSF produces only minor amounts of waste water; and, the RSF and PSF produce very large amounts of waste water.
9. The TSSF is simple to operate but it requires significant effort to clean.
10. The MSSF are simple to operate and simple to clean.
11. The RSF and PSF are complex to operate effectively and relatively simple to clean.
12. The operator skill levels required to successfully operate TSSF and MSSF are relatively low; while, the skill levels required to successfully operate RSF and PSF is quite high.
13. The relative overall costs of operation and maintenance of the TSSF and MSSF is low to very low when compared to the costs of operation and maintenance of the RSF and PSF.

CONCLUDING REMARKS

The MSSF technology eliminates many of the disadvantages of TSSF while providing for operation on a demand basis with cleaning using a backwash process. These features suggest several non-traditional applications for water treatment using slow sand filtration including: treatment of surface water supplies with high suspended solids loads such as those occurring seasonally or after rainfall events, administration of a variety of pre- and post-treatments to remove colloidal clay or natural organic matter (to reduce colour, odour and disinfection by-products); filter water from waste water treatment plants that have been treated to secondary standards for disposal or to a quality suitable for reuse in industry or irrigation; and, to treat water produced in greenhouse applications and food processing applications to a recyclable condition.

The ability to backwash a slow sand filter opens the way to exploit the effectiveness of TSSF to remove very small particulate matter. Several significant water treatment plants located in the Provinces of Alberta and Saskatchewan are using a variation of the MSSF, known as the Manz Polishing Sand Filter or MPF, to remove iron, manganese, iron bacteria and hydrogen sulphide from groundwater (arsenic removal is practical and uncomplicated). There are many other applications for the MPF technology, not bound by most regulatory agencies, but simply by performance.

Both the MSSF and MPF technologies may be inexpensively evaluated using bench scale and pilot scale studies.

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Table 1.0 Sand Filter Comparison.

Characteristic	Traditional Slow Sand Filter (TSSF)	Rapid Sand Filter (RSF)	Pressure Sand Filter (PSF)	Manz Slow Sand Filter (MSSF)
Effectiveness in removing:				
Pathogens Parasites Bacteria Viruses	 Very effective Very effective Very effective	 Possible Not effective Not effective	 Possible Not effective Not effective	 Very effective Very effective Very effective
Particulates Silt Clay Organic	Very effective and practical at low turbidity.	Effective as part of conventional treatment systems. (These include use of coagulants and clarification prior to filtration.)	Effective as part of conventional treatment systems. (These include use of coagulants and clarification prior to filtration.)	Very effective and practical at all turbidities. Pre-treatment may be useful.
Oxidized Iron Manganese	Effective but not usually practical.	Not sufficiently effective or normally used.	Not sufficiently effective or normally used.	Very effective and practical.
Arsenic	Not used because pre-treatment impractical	Not sufficiently effective or normally used	Not sufficiently effective or normally used	Very effective and practical with required pre-treatment
Fluoride	Not used because pre-treatment impractical	Not sufficiently effective or normally used	Not sufficiently effective or normally used	Very effective and practical with required pre-treatment
Dissolved organics	Not used because pre-treatment impractical	Very effective and practical with required pre-treatment	Very effective and practical with required pre-treatment	Very effective and practical with required pre-treatment
Opportunity for Breakthrough	Not possible.	Normal. Used to indicate need to clean.	Normal. Used to indicate need to clean.	Not possible.
Structural Issues				
Relative surface area.	Very large.	Small.	Very Small.	Large.
Relative height.	Deep.	Very deep.	Shallow.	Shallow.
Piping requirements.	Minimal.	Extensive.	Extensive.	Minimal.
Engineering and Construction complexity.	Minimal.	Complex.	Minimal.	Minimal.
Rel. Production Capacity	Community scale.	Community scale.	Small community.	Household to community

<u>Practical Range.</u>		(Impractical at small scales.)	(Impractical at large scales.)	scale.
<u>Rel. Volume Wastewater Production.</u>	Nil.	Very large amounts.	Very large amounts.	Very low amounts.
<u>Operational Complexity</u>	Very Simple.	Complex.	Relatively complex.	Simple.
<u>Relative Construction Cost</u>	Low.	High.	Relatively high. (Usually come as assembled components or package plants.)	Very low.
Need for cover in winter.	Yes.	Yes.	Yes.	Yes.
<u>Relative Operating and Cleaning Cost.</u>				
Manpower – skill level required to successfully operate filter in long term.	Low	High.	High.	Low.
Manpower.	Low but can be significant if water has high conc. of suspended solids. (Not convenient to clean.)	Low.	Low.	Very low.
Method of cleaning.	Manual scraping.	Vigorous backwash usually automatically initiated with filtration to waste.	Vigorous backwash usually automatically initiated with filtration to waste.	Limited backwash intended to clean filter surface layer that may be automatically or manually initiated.
Filter to waste requirements.	Not required (suspended solids and parasites removed without formation of biolayer)	Required to flush filter media and until properly conditioned.	Required to flush filter media and until properly conditioned.	Not required (suspended solids and parasites removed without formation of biolayer)
Chemicals in wastewater.	Nil, as pre-treatment is not practical.	Present because pre-treatment using coagulants is required to achieve system performance.	Typically present because pre-treatment using coagulants is required to achieve system performance.	Nil, if pre-treatment is not used. Pre-treatment is often not necessary for adequate filter performance.
Wastewater generation.	Almost nil.	Very high.	Very high.	Very low.
Energy (pumps, etc.)	Very low.	High.	Very high.	Low.
Overall cost of op/maint.	Low.	High.	High.	Low.