Sustainable Water Production using Biological Water Treatment Processes

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ABSTRACT

The advancements in drinking water treatment over the last 150 years have been primarily driven by the need to improve water quality and to increase production rates. These drivers have led to more complex treatment plants that utilise an array of treatment process and chemicals. However, as society is now focussing on sustainable production, water treatment systems that use biological processes should be re-considered as options for the production of drinking water, in order to reduce energy consumption and chemical use and to minimise waste production. Biological processes for water treatment are not new: the slow sand filters first used in the 19th Century relied as much on biological activity as they did on physical filtration, but their slow filtration rates meant that they occupied a relatively large footprint. Biological water treatment involves the use of naturally occurring microorganisms to improve water quality. Although they are still uncommon, a limited number of full-scale high rate biological processes have been used for treatment of organic and inorganic contaminants in ground water and surface-water, including Iron, Manganese, Ammonia, and Natural Organic Matter. The objective of this paper is to raise awareness of the potential for biological processes as sustainable methods for water treatment and to highlight their advantages, disadvantages, and issues. This will be done by giving examples of existing full-scale biological treatment systems and showcasing the results of recent research in biological processes for water treatment.

KEYWORDS

Drinking Water, Biological Water Treatment, Biological Filter, Biological Activated Carbon, Dissolved Organic Carbon, Endocrine Disrupting Chemicals

1 INTRODUCTION

Although New Zealand has an abundance of good quality water, most raw water sources require some form of treatment before the water can be distributed. Many of the water supplies are from surface water sources and treatment usually involves physico-chemical processes. As implied from the term 'physico-chemical', treatment relies on the use of chemicals and electrical power to produce water that complies with the Drinking Water Standards New Zealand.

Depending on the raw water quality and conditions Biological Water Treatment (BWT) processes can be used either as an alternative to physico-chemical treatment, or to complement physico-chemical treatment. Biological water treatment relies on the ability of non-pathogenic bacteria to degrade organic chemicals and to oxidise inorganic compounds. BWT can be defined as "a process that is partly or wholly dependent on biological mechanisms to achieve water quality treatment objectives" (Vogt et al, 2010).

BWT is not suitable for treatment of all water types. Physico-chemical methods are required for treatment of water with elevated levels of turbidity and suspended solids, and for disinfection of water. However, where BWT can be used, there are advantages of reduced capital and operating costs and reduced waste. BWT can also:

- Reduce chlorine demand
- Reduce production of disinfection by-products
- Reduce the potential for bacterial re-growth in reticulation
- Decrease corrosion potential
- Control taste and odour-causing compounds

(Urfer et al. 1997).

BWT processes are not commonly used outside of Europe, usually due to a lack of awareness or due to the perceived risk of introducing pathogenic microorganisms or by-products into the treated water (AWWA, 2003). However, BWT has the potential to become more frequently used in the future, as increased demand for water forces water suppliers to utilise raw water sources with higher levels of contamination and to treat water in a more sustainable way.

The objectives of this paper are to:

- Raise awareness of the potential for BWT processes as sustainable methods for water treatment
- Provide information on how bacterial water treatment processes work, the range of systems employed and what they can be used to treat
- To highlight the advantages and disadvantages of BWT processes

2 HOW THEY WORK

Comment [AR1]: In each of your sections, summarise the content in the first bit. From this paragraph it is not clear to me that you will talk about food, habitat, etc, so I am unprepared for them and unsure how they fit into the paper as a whole once I get to them.

Biological treatment uses microorganisms, and particularly bacteria, to remove contaminants from water. The types of micro-organism present can vary considerably. The *schmutzdecke* of a slow-sand filter, for example, uses a diverse range of organisms including plankton, algae, diatoms, protozoa and bacteria, whereas iron removal specifically utilises *Gallionella*, *Leptothrix*, *Crenothrix* and *Sidercapsa* (Sommerfeld, 1999).

What is common with all of the biological water treatment options employed is that they rely on the supply of a food source, a suitable habitat in which to grow and a minimum amount of organisms (collectively, the *biomass*) to effectively carry out the treatment.

2.1 FOOD

All microorganism that take part in the BWT process need a source of energy (food) to survive and replicate. Different types of microorganisms require different food sources. In most BWT processes, it is bacteria that remove organic and inorganic contaminants. Higher organisms, such as plankton, feed on bacteria that are in the raw water or that grow in the biomass.

The main food sources that are required for the microorganisms to live and grow are known as primary substrates. Primary substrates may be present in the raw water (e.g. Natural Organic Matter) or they may need to be added (oxygen, ethanol). Secondary substrates such as micro-pollutants may be consumed by the microorganism, but these are not necessary for the microorganisms to live and grow.

BWT processes utilise the substrates, at least one of which is the target contaminant, in oxidation-reduction reactions (Brown, 2007a). The oxidation-reduction reaction involves the transfer of electrons from an electron donor to an electron acceptor. Autotrophic biological processes utilize an inorganic electron donor (e.g., Fe^{2+}) while Heterotrophic biological processes utilize an organic electron donor (e.g., ethanol). The oxidation-reduction reactions convert the substrate into energy, which is necessary for the bacteria to live and reproduce.

Most of the oxidation reactions take place inside the bacterial cell (intracellular), using enzymatic action, though some take place outside of the cell (extracellular) by catalytic action of enzymes that are excreted by the bacteria (Sommerfeld,1999). A simplified version of what occurs in the biological de-nitrification reaction is shown in Figure 1.

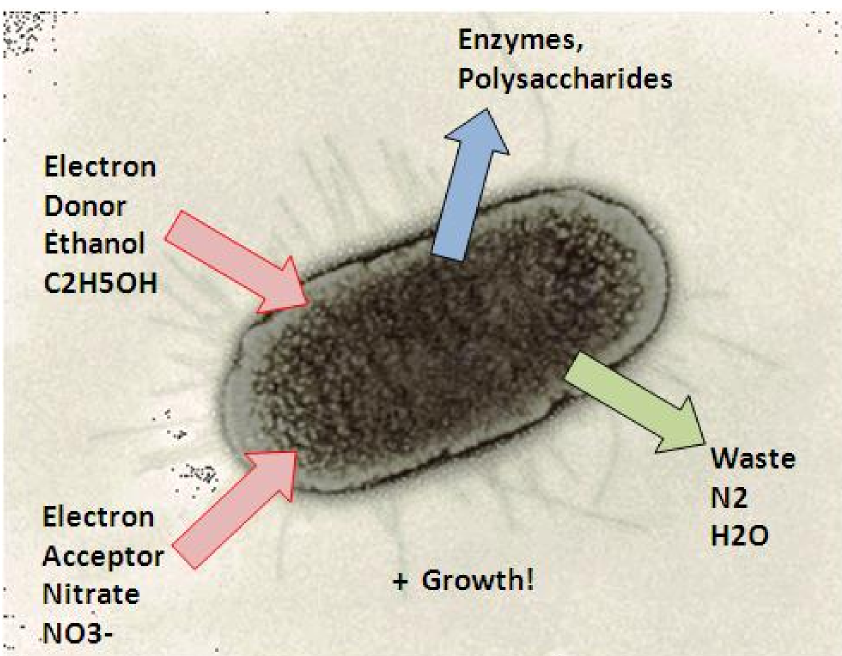

Figure 1: Bacterial-mediated de-nitrification using ethanol as substrate

2.2 HABITAT

Micro-organisms in BWT processes are either attached to a support medium or are free-floating in the treatment reaction vessel. If they are attached to a support media they are known as fixed film and if they are free floating they are known as suspended growth.

Most BWT processes utilise fixed film habitats, which prevent bacteria from being washed out with the treated water. Typically, the bacteria are attached within a biofilm to a support media such as sand or granular activated carbon (GAC) is required. Alternative support media to sand and granular activated carbon have been trialled, including Kaldnes® plastic media, Filtralite expanded clay, calcium carbonate, pumice and anthracite, natural organic solid substrates (including wheat straw) and solid biodegradable polymers (Bayley et al., 2006; Melin et al, 2006; Aslan & Turkman, 2003; Boley et al., 2006; Zhao et al., 2009).

Brown (2007b) reported that a smaller number of BWT processes operate in a suspended growth mode, where free-floating bacteria are maintained within a membrane bioreactor (MBR). However, examples of suspended growth are much less common.

In addition to providing a habitat for the micro-organisms to grow, the water to be treated must also be within the correct temperature and pH ranges and be free of free of compounds that are toxic to the microorganisms. Issues associated with temperature, pH and toxic compounds (inhibitors) are discussed in later on in Section 5.

2.3 BIOMASS POPULATION

To provide effective treatment a sufficiently sized biomass is required. To ensure this is possible, sufficient primary substrates, as well as trace elements, must be present in the feed water. There must also be sufficient surface area of media for support of the biomass. Some media types, such as GAC and expanded clay, have greater specific surface area than others such as sand and anthracite. However, the volume/ depth of media can also be increased to provide more biofilm area.

It is logical to assume that a larger microbiological population will allow greater removal of pollutants. However, hydraulics also need to be considered, as excessive biomass can restrict flow and affect process performance. Removal of biomass by backwashing or scraping off (skimming) the *schmutzdecke* is required to prevent excessive biomass build-up. The removal of biofilm also helps to maintain a healthy population: If biofilms grow too thick, it is more difficult for substrates to diffuse into the layers of biofilm nearest the support media, which in turn causes cell die-off and sloughing of biomass.

3 SYSTEMS

There are numerous types of systems in which BWT processes can be employed within water treatment plants (WTP). This section describes the ones most frequently encountered.

Biological treatment of pollutants can also take place in natural and artificial systems upstream of the treatment plant, e.g. in wetlands, within bore-fields and through infiltration galleries. Treatment systems upstream of the WTP utilise biological-physical processes in very similar ways to those employed at the works. However, this paper is mainly concerned with treatment processes with the systems which are used within WTPs, as described below.

3.1 SLOW SAND FILTERS

The first municipal BWT process was the slow sand filter (SSF), developed in the early 19^{th} century in Europe. Although the Engineers of the time probably did not realise it, the slow-sand process relies as much on microbiological activity as it does physical filtration, to improve the quality of raw water.

In conventional SSFs, most of the biomass forms a sticky layer in the sand in the top few centimetres of the filter. This layer, known as the *schmutzdecke*, performs much of the removal of turbidity, suspended solids and organic matter. However, recent research shows that removal of trace organics may occur throughout the depth of the filter. Details of typical performance of SSFs are given in Table 1.

Table 1: SSF Performance Summary

Water Quality Parameter	**Removal Capacity**
Turbidity	<1NTU
Coliform Bacteria	1-3 log units
Enteric Viruses	2-4 log units
Giardia Cysts	2-4+ log units
Cryptosporidium Oocysts	> 4 log units
Dissolved Organic Carbon (DOC)	< 15-30%
Biodegradable DOC (BDOC)	< 80%
Assimilable Organic Carbon (AOC)	< 65%
THM Precursors	< 20-35%
Iron/ Manganese (Fe/Mn)	< 67%

(From Amy et al., 2006)

Large slow sand filters, such as those shown in Photograph 1, are still used at several treatment plants around London, although the process has been improved and integrated with additional processes, such as upstream rapid sand filters. The low filtration rates of this process meant that a significant amount of land was required to treat water for a large population. The filters also required intensive manual cleaning (as there was no backwash feature). These factors resulted in the decline of the SSF and the development of more chemical and energy intensive water treatment processes. However, there is a renewed interest in implementation of SSF as a tool for meeting the UN's Millennium Development Goals (Amy et al.,2006).

Comment [AR2]: Since you take pains to abbreviate it earlier, continue to do so

Comment [AR3]: Now this is interesting. Who's interested, where would they want to use it, and why are they suddenly interested? I think you could answer all of those questions with just a single sentence rather than leaving us hanging.

Comment [AR4]: Gorgeous!

Photograph 1: Slow Sand Filters

3.2 BIOLOGICAL (RAPID) SAND FILTERS

In Biological (Rapid) Sand Filters (BSF), the biomass is distributed through the depth of the filter. BSFs have been placed upstream of SSFs as roughing filters to reduce the load going onto the SSFs at several water treatment works in London (Chipps et al., 2006). The majority of the roughing filters do use coagulant dosing or upstream clarification processes.

Comment [AR5]: Use or do not use?

Biological iron and manganese removal has also been carried out using BSF, using conventional open filter shells as well as pressure vessels. The main difference in the biological process is the higher flow rates (and hence lower media volume required) and use of coarser sand (1.3mm effective size compared to 0.9mm for physico-chemical treatment (Hall, 1994).

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3.3 FLUIDISED MEDIA FILTERS

Fluidised media filters have been used for heterotrophic processes, as this gives a larger surface area for biomass growth. The higher biomass concentration and high up-flow rates allow smaller reactor volumes and surface areas respectively (Hall, 1994).

Comment [AR7]: What are these?

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3.4 BIOLOGICAL ACTIVATED CARBON FILTERS

Biological Activated Carbon (BAC) filters are in a similar configuration to conventional activated carbon filters, where design is based on Empty Bed Contact Time. However, pre-chlorination is not practiced. Ozone is often used upstream of the filters to provide additional assimilable organic carbon (AOC) as a substrate. Backwashing is carried out every 7-14 days. BAC filtration can utilise conventional open filter shells as well as pressure vessels (as per Photograph 2).

Comment [AR9]: Why would we expect it to be?

Brown (2007b) also reported an MBR process where bio-films grew on the outside of the hollow fibre membranes, which were used to transport hydrogen gas (electron donor) to the biofilm.

Comment [AR10]: And it worked?

Photograph 2:   Biological Activated Carbon Filters utilising pressure vessels

3.5 MEMBRANE BIOREACTORS

Membrane systems can also be utilised in biological treatment. In one approach, ultra-filtration membranes are submerged in a reactor basin that contains suspended biomass. The reactor basin provides the detention time necessary to achieve effective biological treatment. Treated water is drawn through the membranes by vacuum and pumped out to permeate pumps for further processing. Airflow introduced at the bottom of the reactor basin to clean the outside of the membranes, provide oxygen to act as an electron and to maintain suspension of the biomass. Periodic backwashing of the membranes is also carried out by passing permeate through the membranes in the reverse direction to dislodge solids from the membrane surface (Brown, 2007a).

4 WHAT CAN BIOLOGICAL PROCESSES BE USED TO TREAT?

Full-scale BWT processes have been specifically constructed and proven to remove ammonium, iron, manganese, nitrate and perchlorate and Biodegradable Natural Organic Matter (BOM). Biological activity in slow sand filters (SSF), Biological (Rapid) Sand Filters (BSF) and Biological Activated Carbon (BAC) filters has also been demonstrated to remove ammonium, BOM, including taste and odour-causing compounds such as MIB and Geosmin, cyanobacterial toxins, endocrine disrupting chemicals (EDCs), and pharmaceutically-active compounds (PhACs).

Comment [AR11]: Based on your conclusions, if we have a surface water (which is very common in NZ), is it possible we can treat with only biological processes or will we most certainly need physical/chem. too?

Given the range of contaminants that BWT processes can remove, many New Zealand surface waters could be treated by a biological process, provided raw water turbidity levels are not excessive, (<10NTU) followed by UV disinfection and chlorination, without the need for physico-chemical treatment.

A list of contaminants that have been demonstrated to be removed by BWT is given in Table 2. Details of some of the more commonly used applications are given in the following sub-sections.

Table 2: Contaminants Amenable to Biological Water Treatment

Contaminant Category	**Contaminant**
Natural organic matter (NOM)	*Re-growth substrate* *DBP precursors* *Colour* *Membrane foulants*
Trace organics	*2-methyl-isoborneol (MIB)* *Geosmin* *Cyanobacterial toxins* *Endocrine disruptors and pharmaceutically active compounds* *Pesticides* *Methyl tertiary-butyl ether (MTBE)*
Inorganics	*Perchlorate* *Chlorate* *Nitrate* *Nitrite* *Bromate* *Selenate* *Chromate* *Ammonia* *Iron* *Manganese*

	Arsenic

[1]Source: Adapted from Brown (2007b)

4.1 NATURAL ORGANIC MATTER

Natural Organic Matter (NOM) in water can result in re-growth of bacteria in distribution systems and is a precursor for Disinfection By-Products (DBPs). Bio-filtration can remove much of the biodegradable NOM (BOM) . However, some organic pollutants are not readily biodegradable. Pre-ozonation of the NOM has been shown to increase the concentration of assimilable compounds. The increase in assimilable compounds serves as additional substrate and leads to higher biomass contents in filters (Moll et al., 1998). Removal rates of BOM are usually proportional to the influent concentration of the BOM.

NOM, usually measured as Total Organic Carbon is typically in the range of 0.1-2mg/L for groundwaters and 1-20mg/L for surface waters. The fraction of NOM that is biodegradable is often difficult to measure as the test for biochemical oxygen demand (BOD) is not sensitive enough and the assimilable organic carbon (AOC) measurement is difficult and prone to error. TOC removal in BWT processes can vary depending on how much of the TOC is biodegradable and whether ozonation is used. Removal rates are usually in the range of 30-50%, but can be as high as 75% (where ozone is used). However, AOC appears to be better removed by biological than physico-chemical processes (Bouwer & Crowe, 1988).

Biological oxidation of carbonaceous organic matter upstream of membrane processes can also improve trans-membrane fluxes without chemical additives. Peterson (2008) describes how a biological treatment of poor quality groundwater was followed by RO treatment at Yellow Quill in Canada. The RO membranes were cleaned only once in 5 years and had a projected life expectancy of more than 10 years.

4.2 TRACE ORGANICS

Trace organics are often degraded as a secondary electron donor as they do not yield the requisite energy to support cell maintenance and growth. Applications that are required to treat trace organics require the presence of a primary substrate, such as NOM. Secondary substrates typically degrade at a rate related to the amount of biomass present in the system (Snyder et al., 2007).

Pre-ozonation can increase the biomass by providing more primary substrate. However, ozonation has relatively expensive operating costs and can produce by-products such as bromates. An alternative method of increasing biomass on GAC beds was trialled by Brown and Lauderdale (2006), where acetic acid was dosed as a primary substrate. This provided biomass stability and achieved greater than 90% MIB and Geosmin degradation (using 10 minute Empty Bed Contact Time), even when inlet Geosmin and MIB concentrations were intentionally varied between 5 and 50ng/L.

Ho et al., (2006) carried out trials that demonstrated that slow sand filters and BAC filters were effective at removal of the cyanobacterial toxin microcystin and that the lag time prior to degradation occurring was reduced if the bacterial community had previously been exposed to microcystin. Microcystin degradation in slow sand filters may occur not just in the schmutzdecke, but throughout the depth of the filter and that filter maturity, redox conditions and temperature are important (Grutzmacher et al., 2006).

Biological sand filters have been demonstrated to achieve good removal of taste and odour-causing compounds. MIB and Geosmin removal rates of >80% and >50% respectively were observed on biological sand filters at the Greater Cincinnati Water Works over a 6 year period, without pre-ozonation (Metz et al., 2006).

Trace levels of endocrine disruptors (EDs) in water sources and in water supplies have become a matter for public concern within the past 10 years. Many of the EDs are not effectively removed by physico-chemical processes. However, Snyder et al. (2007) reported good removal efficiencies in BAC pilot trials an Brown and Lauderdale (2006) reported the removal of 23 different endocrine disruptors and pharmaceutically active compounds during pilot trials with GAC, percentage removals as high as 83 percent at a 10-minute EBCT.

4.3 AMMONIA

Biological oxidation of ammonium to nitrate (nitrification) operates in a similar way to wastewater nitrification and provides an effective alternative to break-point chlorination. The process utilises autotrophic bacteria and oxygen for the following two-step reaction:

$$2NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas Bacteria}} 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter Bacteria}} 2NO_3^-$$

The reaction requires a temperature of > 8C, a pH of 6.0-8.0 and a dissolved oxygen (DO) level of >1mg/L. If the influent ammonium concentration exceeds 1mg NH_4^+/L the filter media must be aerated. The reaction also consumes 11.2mg of alkalinity for every 1mg of ammonium and so alkalinity may need to be added to prevent the pH from falling below 6.0 (Larson, 1995).

4.4 NITRATE

Biological reduction of nitrate to nitrogen gas can be carried out using heterotrophic bacteria or autotrophic bacteria. Use of heterotrophic bacteria also requires dosing of an organic carbon source (e.g. ethanol) or a solid biodegradable organic support media as a primary substrate. Use of autotrophic bacteria requires dosing of an electron donor, such as: hydrogen gas; hydrogen sulphide; elemental sulphur; thiosulphate; sulphite (Bouwer & Crowe, 1988). The process produces an innocuous end product (N_2), unlike ion-exchange or reverse osmosis which produce a concentrated nitrate waste stream.

Comment [AR12]: orphan

Backwashing of the filter media can be an issue for heterotrophic de-nitrification, as DO in the backwash water can inhibit the process. A heterotrophic biological fluidised bed process was developed by WRc., Anglian Water Services and the Department of the Environment (Hall,1997) that attempted to resolve this issue. The motion of the fluidised sand continuously removed biofilm. However, an additional means of cleaning the sand to remove excess biomass was required.

4.5 IRON AND MANGANESE

The first biological iron and manganese treatment facilities are reported to have been built in Germany in 1874 (Kohl & Medlar, 2006). Biological iron and manganese filtration processes offer several advantages over physico-chemical treatment, including reduced aeration requirement, no requirement for chemical oxidation prior to filtration or settling and much smaller filtration bed area due to the higher filtration rates (Mouchet, 1995). A further advantage of biological iron removal is the significantly greater run time between backwashes and the production of a more readily settleable sludge (Sommerfeld, 1999).

The process utilises autotrophic bacteria to carry out oxidation of soluble species (Fe2+, Mn2+) to insoluble species (Fe3+, Mn4+). Both processes require oxygen as an electron acceptor. Unfortunately, where both iron and manganese are present, the process cannot be carried out in the same filter as the maximum redox potential for biological iron removal is lower than for biological manganese removal. The optimal DO concentration for biological iron removal is approximately 1mg O_2/L at pH 7. If more than 3mgO_2/L is provided, chemical oxidation of the ferrous ion occurs (Ankrah & Søgaard, 2009) leading to filter breakthrough (Larson, 1995). For biological manganese removal, pH of >7.5 and DO of >5mgO_2/L is required (Sommerfeld, 1999). These pH and redox requirements are demonstrated by Figure 2.

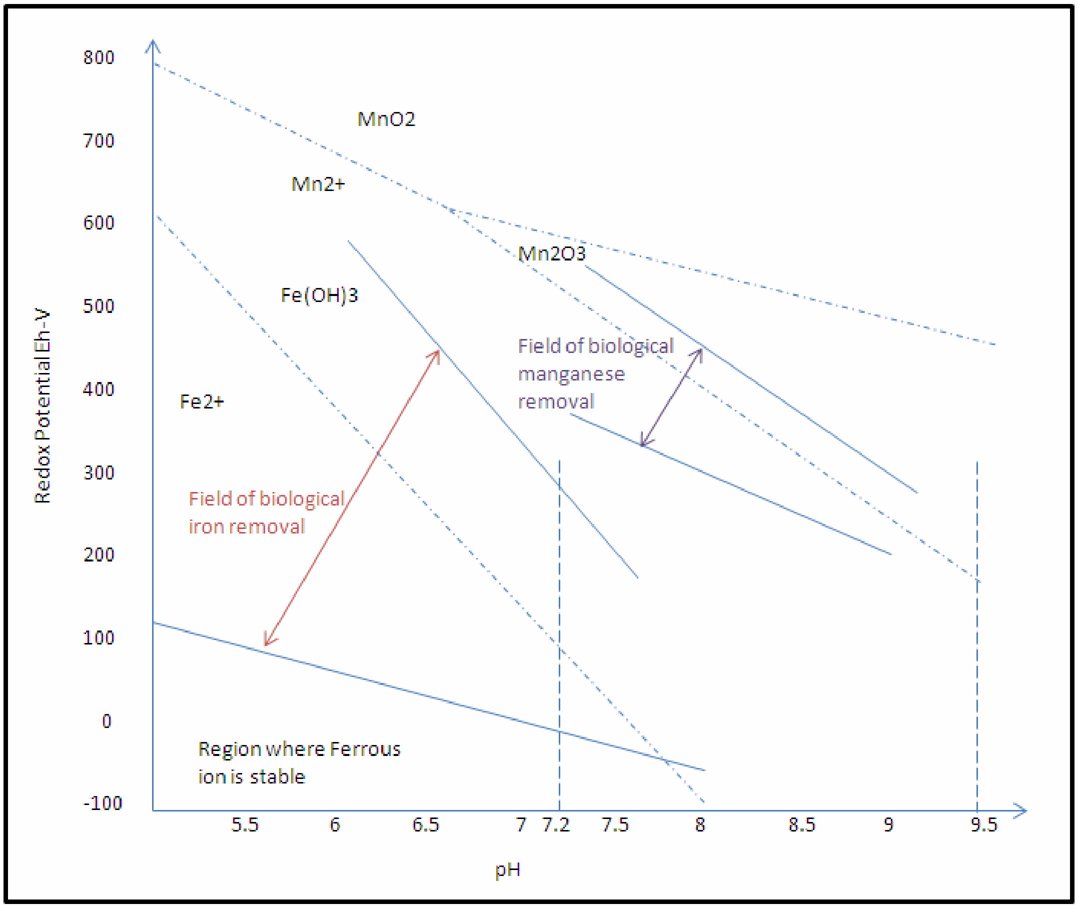

Figure 2: *Field of activity of Iron and Manganese bacteria*

5 CONSIDERATIONS FOR THE IMPLEMENTATION OF BWT PROCESSES

5.1 START-UP AND RECOVERY

Biological processes take time to become established. The time taken for sufficient bacterial numbers to develop for effective treatment will depend on the process employed, the environmental conditions, the type and concentration of target pollutant and the amount of primary substrate present. BAC filters may take >200 days for a biomass, consisting of >10^6 viable cells / g AC to develop (Kim et al.,1997).

Biological filters perform best after an acclimation period and they may become acclimated to one parameter, but not another (Metz et al., 2006). In other words, a biological filter may fully treat pollutant X within a few days of pollutant X first being applied, but may take more than 100 days, after first application, to treat pollutant Y.

Biological iron removal filters normally require 2-3 days, and in some cases up to a week, for sufficient biomass, to become established. Seeding of the filters is not necessary (Sommerfeld, 1999). Biological manganese filters can take up to 8 weeks to become established. However, once established the biomass is reasonably stable and recovery after periods of shutdown is possible within a short period of time (Larson, 1995). Upon return to service following normal periods of shut-down (up to 12 hours), filter run to waste may be required and rapid changes in flow-rate should be avoided.

Conventional SSFs require regular removal of the top layer for cleaning (skimming), as the hydraulic performance of the filter declines. This can be manually intensive and when the filter is returned to service, a run to waste is required to allow the biological community to redevelop. Once the top layer has been removed approximately 6 times, a new layer of sand is placed on the filters to maintain a minimum filter depth. Trials of a robotic cleaning device on SSFs in Sweden have been successful, with the risk of bacterial breakthrough reduced due to less disturbance of the filter bed, as well as quicker recovery of biological activity (Back, 2006).

SSFs are best operated continually, to ensure sufficient oxygen, which is present as DO in the raw water, reaches the schmutzdecke. This problem has been overcome by Manz (2004), who has developed a small scale SSF that can be operated intermittently, by draining to a depth of 5cm above the filter media. The shallow layer of water allows sufficient oxygen to diffuse through to the schmutzdecke. The revised design also includes a gentle surface clean that eliminates the need for skimming.

5.2 ENVIRONMENTAL CONDITIONS

Biological processes may not be suitable for treatment of all types of raw water, as raw water conditions and conditions in the process vessel may discourage biological growth and activity. These factors include temperature, pH and presence of inhibitors to bacterial growth or respiration.

5.2.1 TEMPERATURE

Removal rates of contaminants usually increase with increased temperature, because mass transfer and microbial kinetics are more rapid. Several studies into removal of BOM using biological filters show that steady state removal rates are higher at 20-25°C than at 9-15°C (Urfer et al., 1997).

MIB removal of 50% was observed in biological sand filters after 4 months of operation at 20°C, but no removal was observed at 4°C (Summers et al., 2006). Biological iron removal and manganese removal require a water temperature of >10°C and >8°C respectively (Larson, 1995).

Comment [AR13]: orphans

5.2.2 PH

pH also has an effect on activity, with most processes having optimal pH ranges, outside of which the reaction may be slower, or may not work at all. For example, biological iron removal is inhibited above pH 7 whereas biological manganese removal is inhibited below pH 7.5.

5.2.3 INHIBITORS

Biological activity can also be reduced or stopped by the presence of heavy metals or organic materials in the raw water that are toxic to bacteria. Pre-chlorination may not have a significant effect on the bioactivity of attached bacteria on activated carbon (Kim et al., 1997), but can prevent biological iron removal. Hydrogen sulphide and zinc can also inhibit the biological iron process (Sommerfeld, 2009).

5.3 SUBSTRATE AVAILABILITY

In most of the biological processes discussed, dosing of substrates is not required, although additional aeration may be required for some processes. Some processes, particularly heterotrophic biological de-nitrification, require the addition of a carbonaceous substrate. Autotrophic de-nitrification requires addition of hydrogen gas. Provision of additional primary substrates will increase the cost of treatment, with dose required dependent on the concentration of the target pollutant in the raw water. Safety of dosed substrates also needs to be considered, from storage, handling and water quality perspectives.

5.4 POST TREATMENT

Post-filtration, using rapid gravity filters or membranes may be required to remove bacteria and particulate matter. However, in many full scale plants BAC, biological iron and biological manganese filters are the penultimate stage of the treatment plant prior to disinfection.

Post treatment filtration of the heterotrophic de-nitrification process is required to address issues of continuous biomass carry-over. Aeration, is also required to re-oxygenate the treated water, as the process takes place under anoxic conditions. The carry-over of carbonaceous substrate is also possible. Therefore, GAC/ BAC is also recommended.

All of the biological treatment processes require disinfection, although the chlorine dose is often reduced due to removal of compounds that exert a chlorine demand.

5.5 DWSNZ

Although many of the biological processes have been demonstrated to remove pathogens, including coliforms, *Giardia* and *Cryptosporidium*, any process selected must meet the compliance criteria of Drinking Water Standards New Zealand. Therefore, careful selection of treatment options to achieve the correct number of log credits is required. Design of the treatment process also has to take into account the control of dosing of any substrate to ensure that the Chemical Compliance Criteria 2a is complied with.

6 BENEFITS

SSFs are not common in New Zealand and they may be considered by many to be an obsolete process that takes up much land. However, the World Health Organisation website states:

> *"Under suitable circumstances, slow sand filtration may be not only the cheapest and simplest but also the most efficient method of water treatment. Its advantages have been proved in practice over a long period, and it is still the chosen method of water purification in certain highly industrialized cities as well as in rural areas mid small communities(sic). It has the great advantage over other methods that it makes better use of the local skills and materials available in developing countries, and it is far more efficient than rapid filtration in removing bacterial contamination".*
>
> (WHO, 2010)

The statement made by the WHO identifies some very strong benefits of SSFs: that they are inexpensive, simple, effective and proven. SSFs could be an ideal candidate process for small rural NZ communities, where land is abundant , but skills and capital are in short supply.

It is not just SSF technology that could be of benefit to NZ water supplies, both large and small, rural and urban. Other BWT processes can offer benefits in terms of capital and operational cost savings, use of few chemicals, less waste and improved water quality, as described below.

6.1 CAPITAL COSTS

Although SSF occupies a larger surface area, which implies higher capital costs, there is no requirement for backwash and air-scour systems, backwash handling facilities or chemical dosing equipment. Although pilot tests for SSFs should be carried out prior to design, the cost of setting up a SSF pilot plant is low.

Flow-rates of up to 50m/h are possible with biological iron and manganese removal whereas flow rates of 5-20m/h are common for physico-chemical iron and manganese treatment. Therefore, it is possible to considerably reduce the size of the filtration vessels. Aeration does not need to be excessive and can be achieved using a venturi method on the inlet pipework. This means that aeration/ reaction tanks are not required. Chemical oxidant addition is not require, so the costs of chemical dosing equipment are removed and the process takes place on sand media instead of expensive exotic media such as greensand or manufactured media.

Biological de-nitrification has comparable capital costs to ion-exchange and reverse osmosis, but does not have the additional capital costs associated with treatment of a concentrated waste stream.

Biological activated carbon filtration does not cost any more than conventional GAC treatment (unless pre-ozonation is installed). However, BAC filters have been operated for up to 8 years in the Anglian Water region, without the need for replacement or regeneration of the activated carbon. Before conversion to BAC, the GAC in the filters was replaced or regenerated every 1-2 years. The cost of GAC replacement or regeneration was usually included in the capital budget.

6.2 OPERATING COSTS

SSFs require less driving head than RGFs and do not require backwash or air-scour, resulting in lower energy costs. The process also operates without coagulant and polymer dosing.

Biological iron and manganese removal operate with reduced aeration requirement and filters operate for longer between washing than physico-chemical iron and manganese removal. Chemical oxidation is not required and chlorine dose required for disinfection is also usually reduced. These factors result in lower operating costs.

Biological nitrification produces final water that does not require break-point chlorination, thus reducing chlorine costs.

6.3 FEWER CHEMICALS

Biological treatment processes generally use fewer chemicals. This has an operational cost benefit as described above. However, there are other benefits of using fewer and smaller quantities of chemicals. Lower chemical usage results in reduced CO_2 emissions associated with the production and delivery of those chemicals. Perhaps more importantly to some, the use of fewer chemicals provides a social and cultural benefit.

6.4 LOWER IMPACT WASTE STREAM

Biological iron, manganese and nitrate treatment processes produce smaller quantities of waste that are easier to treat and dispose of because they do not contain aluminium from coagulation or high levels of brine or nitrate and do not usually require pH adjustment. The waste streams, therefore, have less impact on the environment as well as costing less to manage.

6.5 IMPROVED WATER QUALITY

Biological treatment processes allow the production of a biologically and chemically stable treated water. This reduces re-growth in the reticulation. Efficient removal of iron and manganese will also reduce the amount of iron and manganese entering the reticulation. Treatment using BAC effectively reduces taste and odour causing compounds and prevents formation of disinfection by-products. Overall the improvement in water quality should result in health benefits to the community that is supplied.

In addition to improved water quality, these benefits may also result in lower operating costs associated with investigating and resolving customer complaints regarding taste, odour and appearance.

7 THE FUTURE FOR BIOLOGICAL WATER TREATMENT

7.1 RESEARCH

Much of the research and implementation of BWT processes has been carried out in Europe and the US, where water suppliers are increasingly faced with the challenge of treating poorer quality water in order to meet demand for new water sources reliant on groundwater sources. As the demand for water increases, both overseas and in New Zealand, it is likely that water suppliers will turn to sources that were previously considered unsuitable due to contamination. The contamination may be treatable by existing BWT process, but is also possible that new biological processes may be developed to meet future challenges.

Interest in BWT processes may have waned slightly in the late 1990's, however, the need to increase energy-efficiency and reduce CO_2 emissions has prompted renewed interest. This is reflected by new sponsorship for Ph.D and Eng.D positions at the University of Glasgow and Cranfield University in the UK.

Recent breakthroughs in life sciences, molecular microbiology and microbial ecology have identified new scientific techniques, which can now examine microbial communities and predict their behaviour, function and activity. The development of new genomic techniques and predictive mathematical models could allow for better design and optimisation of BWT processes, to improve their performance and reduce the impact of some of the issues described above.

7.2 ARTIFICIAL CELLS

Researchers at the J. Craig Venter Institute (JCVI), made a press release on 20th May describing the successful construction of the first self-replicating, synthetic bacterial cell. The team claim that the result is proof of the principle that genomes can be designed using a computer, chemically made in the laboratory and transplanted into a recipient cell to produce a new self-replicating cell controlled only by the synthetic genome.

Dr Venter told the BBC News "I think they're going to potentially create a new industrial revolution," (Gill, 2010). This may or may not be true, but it opens up the opportunity for bacterial cells to be specifically designed to improve the performance of existing BWT processes or to make possible the treatment of contaminants that are currently only treatable by physico-chemical methods.

The research raises many ethical questions, such that it prompted President Barack Obama to ask the Presidential Commission for the Study of Bioethical Issues to look at the issue. Obama wrote:

> *"In its study, the Commission should consider the potential medical, environmental, security, and other benefits of this field of research, as well as any potential health, security or other risks. Further, the Commission should develop recommendations about any actions the federal government should take to ensure that America reaps the benefits of this developing field of science while identifying appropriate ethical boundaries and minimizing identified risks."*
>
> (Fox, 2010)

However, there are already a range of techniques for genetically engineering a range of organisms, but none have been used for water treatment. So it remains to be seen whether approval will ever be given for artificial cells to be developed and used for a specific BWT process (or whether it will be socially acceptable or economically viable to do so).

8 CONCLUSIONS AND RECOMMENDATIONS

Biological processes may be much more suitable for treatment of some New Zealand waters than physico-chemical processes. Physico-chemical processes may still be required for waters which have high levels of turbidity and suspended solids removal and for disinfection. However, physico-chemical processes may also be combined with biological processes, so that the overall process becomes more sustainable. Biological water treatment processes are likely to have an increasingly important role in the future, as they can provide a more sustainable method of meeting water quality objectives in a quadruple bottom line context:

Economical: Biological processes have low capital and operational costs. They also provide the opportunity to increase the effectiveness and reduce the operational cost of other processes, such as reverse osmosis.

Environmental: Biological processes are less energy-intensive than conventional processes. Another benefit of some biological processes is the reduction of waste volume (which also means more efficient use of water) and reduced chemical use.

Social: Most people do not consider the quality of the water that comes out of their taps, unless it has a bad or unusual taste, smell or appearance.

Cultural: Using biological processes may also reduce or eliminate the need for addition of treatment chemicals, resulting in a water supply that is culturally more acceptable to some communities.

We are fortunate in New Zealand that we are water-rich, both in quality and quantity. However, as the demand for water grows, and as energy costs increase, biological water treatment processes may prove to be a more sustainable method of exploiting lower quality water sources. An increase in the understanding of these processes through research, better implementation through new technology and a greater awareness of what these processes can offer will all contribute to their future use.

Biological treatment processes should be considered wherever source water contains elevated levels of biologically treatable contaminants, including natural organic matter, nitrate, iron, and manganese. Where a biological process is proposed for treatment of a particular contaminant, or range of contaminants, it is recommended that pilot trials are first carried out to ensure that the environmental conditions required for successful operation are present.

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