REMOVAL OF VIRUSES AND ENDOCRINE DISRUPTERS ACROSS THE MBR PROCESS

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ABSTRACT

Bacteriological indicators such as Faecal Coliforms and their removal across various wastewater treatment processes is well documented. However, it has been noted by a number of public health researchers that viruses present a significant risk to community public health and industry (i.e. the shellfish industry) and there is little information on their removal and currently no recognised accurate indicator test. Virus testing is expensive at present, but over the past 10 years testing procedures have become more specific as knowledge has increased.

As knowledge of the effects of wastewater discharges on the receiving environment increases and with the requirement to continually improve effluent quality, Membrane Bioreactor technology has recently been implemented for wastewater treatment at a number of locales in New Zealand.

In this paper we present details of recent findings of virus and endocrine disrupters across the MBR process. MBR plants effluent quality data is compared to removals typically achieved across conventional treatment systems (particularly activated sludge variants) with Ultraviolet disinfection.

KEYWORDS

Wastewater treatment, wastewater recycling, conventional treatment system, UV disinfection, membrane bioreactors, particle size, viruses, endocrine disrupters

1 INTRODUCTION

Faeces from humans and animals carry many disease-causing organisms. Wastewater also may contain harmful chemicals, hormones and heavy metals leading to a variety of environmental and public health risks. Evidence suggests that environmental exposure to some anthropogenic chemicals may result in disruption of endocrine systems in human and wildlife populations. Disease-causing organisms (pathogens) from humans can enter a community's wastewater from hospital patients, or from anyone who is sick or a carrier of disease. Animal wastes often enter from farms, meat packing and processing facilities, and from rats and other animals found in or around sewage or sewers.

In recent years, some scientists have proposed that certain chemical compounds found in wastewater might be disrupting the endocrine system of humans and wildlife. Laboratory studies have found some of these compounds disrupt the endocrine systems of animals and compelling evidence shows that endocrine systems of certain fish and wildlife have been affected by chemical contaminants, resulting in developmental and reproductive problems.

Much of our wastewater, treated or untreated, eventually ends up in our rivers, streams, lakes, and oceans sometimes via groundwater, the underground water source we tap for well water.

When untreated wastewater reaches a drinking water source for the community, there can be significant health risks. The effectiveness of drinking water treatment can be reduced when water is heavily contaminated with waste. To ensure safe drinking water, communities need both effective water and wastewater treatment. In addition, communities need to make sure that untreated wastes are not disposed of improperly on land where people can come in direct contact with it or where it can attract disease-carrying insects or animals (Lewis et al., 1993).

Microbial loading from wastewater treatment facilities can adversely affect the sanitary quality of recreational and shellfish growing waters. Increasingly public health official's harbour growing concerns about the impacts of microbial loading on the aquatic environment from wastewater treatment plants, particularly in relation to the potential it holds to negatively impact on the health status of communities. Many New Zealanders use the aquatic environment for recreational purposes and as a source of seafood and this is an important resource to protect and maintain. Importantly low depravation indexed communities rely on seafood as a sustainable means of enjoying a high protein diet. This means that we need to strive for enhanced wastewater treatment in areas susceptible to degradation of this resource.

Notwithstanding treatment processes a cocktail of pathogens, that exceed infective dose levels and which have withstood processing, can be discharged in the final effluent. The relevance thereof is that in New Zealand, resource consents are granted for treated effluent to be discharged directly or indirectly to the aquatic environment. In may cases this may well be the most cost effective option but not necessarily the best public health outcome. Efforts to achieve a balanced outcome is not new and has tested the resolve of engineers, scientists and public health officials for a considerable time.

Historically the conventional approach to determine the performance of treatment plants has been measured using indicator bacteria [coliforms, e.coli], BOD [biochemical oxygen demand] and suspended solids. These indicators have failed to stem the tide of gastro intestinal disease, which has continued relatively unabated, particularly in respect of non-culturable viral pathogens. In the viral group, norovirus status as a human pathogen has risen to a point where it is the most significant cause of gastroenteritis in many countries.

Notwithstanding intensive research to provide a scientifically defendable approach to assessing a treatment process ability to inactivate organisms like norovirus, or determine the organism's active or inactive status when leaving the treatment facility, we have not reached a point where this has been reliably and cost effectively achieved.

2 DISEASES PATHWAYS RELATED TO WASTEWATER

Humans can "catch" diseases from wastewater in a variety of ways. Pathogens in wastewater may be transmitted by direct contact with sewage, by eating food or drinking water contaminated by sewage, or through contact with human, animal, or insect carriers.

For example, direct contact might accidentally occur as a result of walking in fields fertilised with untreated wastes, playing or walking in a yard with a failed septic system, touching raw sewage disposed of in open areas, swimming or bathing in contaminated water, or working with or coming into contact with animals or wastewater and not following proper hygiene.

By far the most common way that people contract diseases from wastewater is through the faecal-oral route, or in other words, by eating contaminated food or drinking water or by not washing hands after contact with sewage.

In communities where wastewater treatment is inadequate or nonexistent, the opportunities for people to become infected seem endless. For example, people have become ill by doing the following:

- Drinking water, juices, or other beverages contaminated by sewage
- Eating food improperly handled by infected people or carriers (often workers in restaurants or food processing facilities)
- Eating vegetables and fruits contaminated by irrigation with polluted water or fertilised with untreated sewage or sewage sludge
- Eating meat or drinking milk from animals that grazed on contaminated pasture or drank contaminated water
- Eating fish or shellfish grown, caught, or harvested in contaminated water
- Eating food exposed to flies or vermin that feed on or come into contact with sewage

Diseases contracted by drinking contaminated water or eating contaminated food are often referred to as waterborne and foodborne diseases.

Bacteria, viruses, and parasites (including worms and protozoans), are the types of pathogens in wastewater that are hazardous to humans. Fungi that can cause skin, eye, and respiratory infections also grow in sewage and sewage sludge. Scientists believe there may be hundreds of disease-causing organisms present in sewage and wastewater that have yet to be identified (National Small Flows Clearinghouse, Pipeline 1996).

Shellfish grown and harvested in virus infected waters tend to concentrate the viruses and bacteria in their edible tissues, and concentrations of these microorganisms in shellfish may be expected to be much higher than in surrounding waters (Bosch., 1998).

2.1 VIRUSES

2.1.1 THE DIFFERENCE BETWEEN VIRUSES AND BACTERIA

A virus is any group of ultramicroscopic agents that reproduce only in living cells. Unlike viruses, bacteria do not require a living host cell to reproduce. Pathogenic bacteria are microscopic in size and common in wastewater. Microorganisms can be present in large quantities in the wastewater collection system and treatment process(Clark, C.S.,1987).

2.1.2 TYPES OF VIRUSES FOUND IN WASTEWATER

Viruses multiply in the living cells of the intestinal tract and end up in human faeces. The common human viruses in wastewater include Caliciviridae (Norwalk and other such small round structured viruses), Reoviridae (Reovirus and Rotavirus), Adenoviridae (Adenovirus), Picornaviridae (Enteroviruses – {Coxsackie A and B, Echovirus, Poliovirus}, Hepatitis A), and Astroviridae (astroviruses).

The following provides further detail on many of the above virus types in more detail (Biological Consulting Services inc.):

- Adenovirus - Non-enveloped, double-stranded DNA virus, 60-90 nm. May cause gastroenteritis.
- Calicivirus - Non-enveloped, plus-sense RNA virus, 26-32 nm. Major cause of viral gastroenteritis.
- Coronavirus - Enveloped, plus-sense RNA virus, 80-200 nm. Causes primarily an upper respiratory disease. However, the virus has been found in the stool of individuals with diarrhea.
- Enteroviruses - All in the picornavirus family. Non-enveloped, plus-sense RNA viruses, 22-30 nm. Viruses of human origin within this group include, Poliovirus, Coxsackievirus (type A and B), Echovirus, Enterovirus 68-71. These viruses can be transmitted through the oral-fecal route and many have the ability to target the central nervous system. Enteroviruses can produce a large number of clinical symptoms depending on the type of virus. These include, myalgia, pancreatitis, diabetes, myocarditis, hand-foot-and-mouth disease, conjunctivitis, and gastroenteritis among others.
- Hepatitis A virus - Also in the picornavirus family. Non-enveloped, plus-sense RNA virus. Major cause of viral hepatitis.
- Reovirus - Non-enveloped, segmented double-stranded RNA virus, 65-75 nm. Can be found in water or sewage. Possible enteric pathogen.
- Rotavirus - Non-enveloped, segmented double-stranded RNA virus, 65-75 nm. Major cause of viral gastroenteritis.

These viruses have the potential to cause gastrointestinal and upper respiratory illness when proper safety procedures are not followed in the workplace. There are over 150 different types of enteric viruses found in raw sewage. This is dependant on several factors, such as the time of the year and community present species.

2.1.3 INDICATOR ORGANISMS

Current resource consents in New Zealand most often refer to indicator organisms rather than a specific virus, often F – Specific Bacteriophage which are viruses that infect bacterial cells. There are a variety of these viruses called coliphage, which may infect bacteria species such as Escherichia Coli. These phages are commonly present in wastewater in relatively large numbers as compared to enteric animal viruses. The F - Specific Bacteriophage is the main indicator organism currently used in New Zealand, although several coliphage indicators have been suggested as being appropriate as a viral indicator (Donnison et al, 1995). This appears be due more to ease and cost of analysis than actual equivalency with enteric viruses.

2.1.4 DETECTION METHODS

Enteroviruses, hepatitis A virus (HAV) and other enteric viruses can survive wastewater treatment processes, even after chlorination, and can be found in the final effluents. These viruses can be detected by cell culture techniques with observations for cytopathic effect (CPE). Recently molecular detection of viral nucleic acids has been used. Most viruses found in wastewater are RNA viruses and Reverse Transcriptase Polymerase Chair Reaction (RT-PCR) is a rapid and sensitive method to detect these single-strand RNA enteric viruses. This methodology does not distinguish between infectious and non-infectious viruses. Viruses inactivated in the treatment process are detected by this test but do not pose a public health threat. Methods are needed to quickly distinguish the infectious viruses from inactivated viruses, both of which may be present in effluents.

Other methods investigated include a method that combines cell culture and molecular detection. If a sample contains viruses that replicate in cell culture even without CPE, the proof of replication can be demonstrated by the detection of a replicative form (RF) in cell culture that is only present during replication of infectious RNA viruses. A negative sense strand of RNA is generated from the viral positive strand virus, and these two are found primarily bound in a replicative form.

2.1.5 VIRUS SIZES

Protozoa are likely to be removed by filtration, owing to their comparatively large size (e.g. *Giardia* 10–20 µm), compared to bacteria, (e.g. *E. coli* 2–6 µm, or *Enterococcus faecalis* 0.5–1 µm), viruses, (e.g. enterovirus 0.025–0.085 µm, and calicivirus (e.g. Norwalk-like viruses) 0.027–0.040 µm).

Figure 1.0 presents particle sizes of various elements including viruses and the associated filter elements required to remove the various particles.

This would suggest that the microfiltration membranes generally used in the MBR process are not sufficient for effective virus removal. However a wealth of evidence suggests that the filtration properties are enchanced via formation of a dynamic layer of biomass on the membrane surface.

2.1.6 VIRUS DESTRUCTION

Disinfection via UV, Chlorine or Ozone are obvious answers to destruction of viruses in wastewater, however in New Zealand the major focus is on the installation of UV treatment systems, and as such this is only evaluated at this stage. A barrier method such as a Membrane Bioreactor system may also provide a method of removing viruses from effluent discharges.

3 MEMBRANE BIOREACTORS

Membrane bioreactors combine conventional biological treatment with membrane separation to produce a very high quality of treated effluent. Treatment plants are very compact and have low requirements for operator attention compared with conventional sewage treatment plants. Membrane Bioreactors have a compact footprint, low sludge production, and reduced capital costs compared to conventional systems. However membrane bioreactors have higher power consumption costs compared to conventional systems.

Membranes are made up of permeable media (there are several generic types and brands available on the market) which typically has a nominal pore size of between 0.1µm and 0.4µm. Particles in this size range, such as bacteria and protozoa are retained and concentrated within the bioreactor by the membrane whereas smaller particles (i.e. water molecules) pass through the membrane material.

The media material acts as a filter, however as a dynamic layer of biomass and proteinaceous matter accumulates on the surface of the media the effective pore size is reduced which further enhances filtration by reducing the effective pore size.

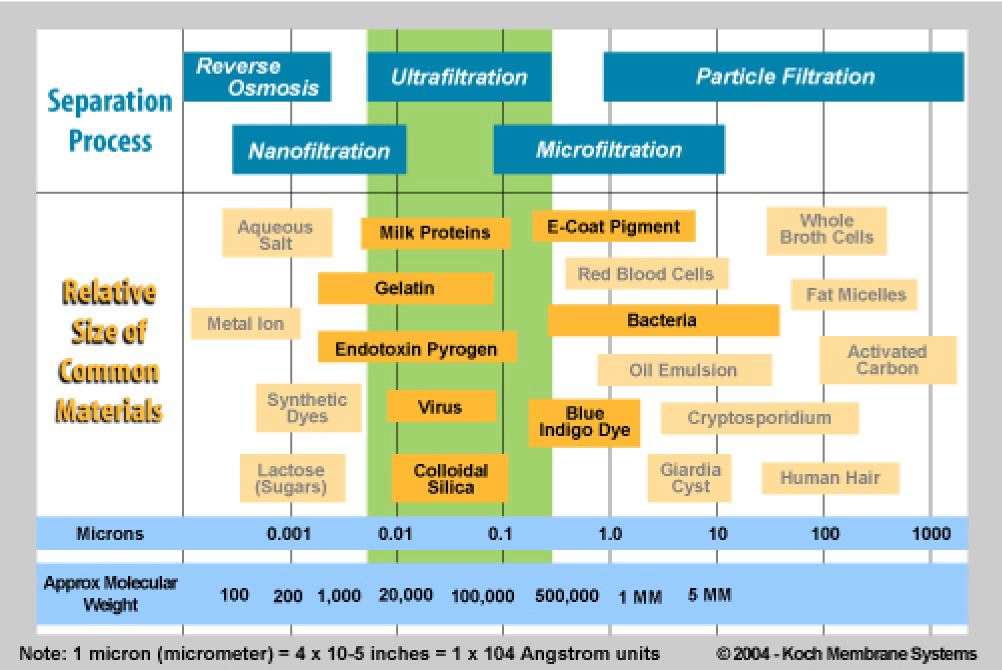

Figure 1.0 Relative Particle Sizes (Koch, 2004)

Given the particle sizes presented in Figure 1.0 it is obvious that a barrier that has an effective pore size smaller than the smallest virus particle should remove all virus particles. From Figure 1.0 above it is evident that limited removal potential exists across microfiltration membranes without a dynamic (a year of biomass and other material) on the membrane surface.

Case studies on virus removal through membranes are given below in many instances they relate to coliphage, and in the case of a membrane barrier system this is thought to be the most accurate of indicator organisms due to its small particle size (0.025 micron being one of the smallest viruses). It is also thought that the mass-transfer in the membrane module may be the limiting factor affecting virus rejection (Urase et al, 1993).

Membranes for wastewater treatment currently come in two generic forms, tubular or flat sheet. An evaluation is given below of the results from previous studies investigating both types of membranes.

Work undertaken by Urase et al., (1994) presented a pore size for a tubular membrane of approximately 0.004 – 0.005 micron.

It should be noted that both of the above studies identified that the real penetration may be as high as 0.02 micron and that a portion of abnormal pores were evident with an effective pore size of up to 0.1 micron which will have a major effect on the rejection (or not) of virus particles. An effective pore size of 0.02 micros is small enough to block virus types wherever most viruses will pass through a pore of 0.1 micro.

According to electron microscope work undertaken (Hama et al., 1987), the flat sheet membrane evaluated had a narrow pore size distribution of 0.008 – 0.009 micron.

3.1 VIRUS UPTAKE IN BIOMASS

A major question is whether there is removal of viruses within the biomass. This process cannot be undertaken via intracellular means as viruses will only infect live human host cells which are not apparent in wastewater. Therefore the mechanism may be via either immersion within the biomass cells or via predation from higher order organisms (i.e. Protozoa) breaking down the viral protein structure as a source of food.

For example, a study undertaken at the Watercare Mangere Wastewater Treatment Facility (Jacangelo et al.,) presented virus removals in the secondary treatment process. Also studies undertaken in soils have indicated that due to the small size of viruses and its surface properties that removal is primarily through adsorption to the particles rather than straining and other effects (Corapcioglu et al., 1984). There is sufficient evidence to show uptake within the biomass however there is little evidence differentiating uptake within the biomass of MBR plants as opposed to more conventional treatment methods. It is thought that viral uptake may be higher in MBR plants than conventional activated sludge plants due to the biomass concentration and the longer sludge age of the biomass resulting in a higher proportion of higher order organisms (e.g. Protozoa) that may predate upon viruses.

4 ENDOCRINE DISRUPTORS

4.1 THE ENDOCRINE SYSTEM

The endocrine system, also referred to as the hormone system, is found in all mammals, birds, and fish. It is made up of:

- Glands located throughout the body.
- Hormones (i.e., chemical stimuli) that are produced by glands and released into the bloodstream or the fluid surrounding cells.
- Receptors in various organs and tissues that recognise and respond in various ways to the hormone stimuli.

Hormones are released by glands and travel throughout the body searching for cells that contain matching receptor proteins within the target cell or located on the surface of the target cell. The hormone binds with the receptor, much like a key would fit into a lock to unlock a door. The hormones (or keys) need to find compatible receptors (or locks) to work properly. Although hormones reach all parts of the body, only target cells with compatible receptors are equipped to respond. Once a receptor and a hormone have bonded, the receptor carries out the hormone's instructions by either altering the cell's existing proteins or turning on genes that will build a new protein. Both of these actions create reactions throughout the body. Researchers have identified more than 50 hormones in humans and other vertebrates (WHO, 2002).

The endocrine system regulates all biological processes from the conception of an organism through adulthood and into old age regulating many functions of a body, including metabolism, blood sugar levels, growth and function of the reproductive system, and the development of the brain and nervous system. The female ovaries, male testes, and pituitary, thyroid, and adrenal glands are all endocrine glands (WHO, 2002).

The *EPA's Endocrine Disruptor Screening Program* focuses on the estrogen, androgen, and thyroid hormones. Estrogens, produced primarily by the ovaries and in small amounts by the adrenal glands, are the group of hormones responsible for female sexual development. Androgens are substances responsible for male sex characteristics. Testosterone, the sex hormone produced by the testicles, is an androgen. The thyroid gland secretes two main hormones, thyroxine and triiodothyronine, into the bloodstream that stimulate all the cells in the body and control many biological processes such as growth, reproduction, development, and metabolism (WHO, 2002).

4.2 ENDOCRINE DISRUPTION

Disruption of the endocrine system can occur in various ways. Some chemicals can mimic a natural hormone, fooling the body into over-responding to the stimulus (e.g., a synthetic growth hormone taken that results in increased muscle mass in body builders) or responding at inappropriate times (e.g., producing insulin when it is not needed). Other endocrine disrupting chemicals can block the effects of a hormone from certain receptors. Still others can directly stimulate or inhibit the endocrine system, causing overproduction or underproduction of hormones. Certain drugs are used to intentionally cause some of these effects, such as birth control pills. In many situations involving, an endocrine effect may not be desirable.

In recent years, some scientists have proposed that compounds found in wastewater discharges to the environment might inadvertently be disrupting the endocrine system of humans and wildlife. A variety of chemicals have been found to disrupt the endocrine systems of animals in laboratory studies, and compelling evidence shows that endocrine systems of certain fish and wildlife have been effected by chemical contaminants, resulting in developmental and reproductive problems. However, the relationship between human diseases of the endocrine system and exposure to environmental contaminants is poorly understood and scientifically controversial.

The presence of endocrine disrupting chemicals (EDCs) in our environment raises concerns because:

- harmful effects have been observed on reproduction, growth and development in certain species of wildlife,
- there are increases in the incidence of some human reproductive disorders and some cancers which could be related to disturbance of the endocrine system, and
- adverse effects from some environmental chemicals known to act on the endocrine system have been observed in laboratory animals (WHO, 2002).

4.3 ENVIRONMENTAL EFFECTS

The following list provides examples of how various species are effected by endocrine disruptors (WHO, 2002):

Mammals: exposure to organochlorines (PCBs, DDE) has adversely affected Baltic seals' reproductive and immune systems, causing large population declines. These seals show signs of damaged endocrine systems, but exactly how these chemicals are causing these effects is not known.

Birds: Eggshell thinning and altered sex organ development have been observed in birds of prey exposed to the pesticide DDT, resulting in severe population declines. Birth defects have been found in fish-eating birds, which are directly related to exposure to another chemical, PCB, but the precise linkage to the possible underlying endocrine disturbance is uncertain.

Reptiles: A presumed pesticide spill in Lake Apopka (Florida, USA) provides an example of potential endocrine disrupting chemical (EDC) effects on the decrease in alligator numbers. The alligators had a variety of sex organ and other developmental abnormalities attributed to exposure to high levels of various organochlorine contaminants that can affect the endocrine balance. Even though several explanations have been proposed, the precise cause of the changes in the alligators remains unknown.

Amphibians: Population declines in amphibians, such as frogs, have been seen in both unpolluted and polluted habitats worldwide. Currently, there is not enough information to know whether EDCs are the cause.

Fish: There is extensive evidence that chemicals found in the waste outflows from pulp and paper mills and sewage treatment plants can affect reproduction and development in fish. A variety of endocrine changes are involved, but it is not yet fully clear which chemicals are responsible for the changes or how they work.

Invertebrates (animals without backbones) : Exposure to tributyltin (TBT), a chemical used in antifouling paints, provides the clearest example in invertebrates of an endocrine effect caused by an environmental contaminant. The females of certain marine organisms, such as snails, slugs, whelks and periwinkles, develop male sex organs when exposed to TBT. This has resulted in worldwide declines in their populations. This ‘masculinisation effect’ is probably due to increases in the levels of male hormones in the females stimulated by TBT.

Not only steroid hormones in human and animal excretions (e.g estradiol, estrone, estriol) and contraceptives (e.g ethinylestradiol) but industrial chemicals can adversely effect the endocrine system. Synthetic chemicals of hormonal effect include pesticides, plasticizers, chemicals in anti – fouling agents, and chemicals in surfactants widely used in cleaning products (and their by – products).

4.4 MBR EVALUATION – ENDOCRINE DISRUPTERS

It is thought that the high sludge age and high solids concentration within the MBR system provides for more effective degradation of endocrine disruptors. Wintgens et al. undertook a study investigating the effectiveness of an MBR plant at reducing/removing endocrine disruptors compared to more conventional treatment systems. Whilst the MBR process was shown to be effective at removal of many of the endocrine disruptors they evaluated, they were unsure as to the removal mechanism. It is unclear if the mechanism was via physio – chemical means, biological means or both.

5 LITERATURE REVIEW

The following outlines a literature review undertaken to evaluate the potential for removal of viruses and endocrine disruptors using the Membrane Bioreactor process and attempts to provide some comparison with conventional treatment methods.

5.1 MBR EVALUATION - VIRUSES

A pilot plant was set up by Farahbakhsh and Smith[i] to evaluate the performance of microfiltration units in removing bacteria and viruses. A membrane made from polypropylene materials and pore size of 0.2μm was used in the experiment. The study found that the overall coliphage removal of the pilot plant varied from 0.2 to 3.4 logs. In addition, the study also found that the coliphage removal mechanism for a clean membrane differs from that of a fouled membrane.

This study also compared UV and MBR, and found that both methods were comparable, each providing up to 3.4 log removal or deactivation of coliphage.

Cote et al., (1997) undertook a pilot plant study which provided results for Bacteriophage removals of 3.8 – 4.5 log. This was undertaken using hollow fibre membrane pore sizes from 0.1 – 0.4μm.

Studies by Lv et al (data) used membranes of different pore size (0.22μm and 0.1μm) to evaluate the relationship between membrane pore size and virus removal performance. The test parameter used in the study was viewed under an Atomic Force Microscope to determine the average virus size was 0.1079 μm. The study found the cake/gel layer formed on the 0.22μm membrane surface was not adequate to remove all phages in the beginning of the trial, with a 2 log concentration still present in the effluent (it should be noted that the influent to the plant was concentrated up to 10^8PFU/ml). However as time passed the effluent concentration of phage decreased and stabilised at a concentration of 0.2 log.

The study inferred that the cake layer formed on the membrane surface reduced the effective pore size of the membrane. It was also inferred that both pathogenic bacteria and viruses were usually absorbed onto the surfaces of the biomass making them more stable, which is a distinct advantage over alternative conventional processes. This process was both via inactivation in activated sludge (which is likely to be similar to the conventional processes) and adsorption into the cake/gel layer. Also inactivation by extracellular enzymes, phagocytosis by bacteria and protozoans, and lysis in activated sludge lead to loss of phage in the bulk solution. It is expected that given the more stabilised nature of the activated sludge in the MBR process that phagocytosis processes will be enhanced compared to activated sludge processes.

A scanning electron microscope showed that a ‘used’ 0.22 /um membrane was covered in bacteria and biopolymers making it difficult for the phages to pass through. In comparison, the smaller size membrane used in the study (0.1μm) was effective at removing phages from the beginning of the trial.

The study found that by selecting a membrane with a mean pore size slightly smaller than that of the target virus, complete viral removal could be expected in a well running MBR system.

Chiemchaisri et al. (1992) found that 4 – 6 log removal of phages was possible through the MBR process. Initial experiments undertaken by Ueda et al. (1999) presented a 3-4 log removal within 800 minutes of the project commencement using the Kubota flat sheet microfiltration membranes (0.4µm). Given the removal in the biomass within the process Ueda found that the Kubota MBR process would achieve at least a 4 – log removal.

Studies by Shang et al., (2005) indicated an increase in phage removal with both an increase in solids concentration and solids retention time (SRT) with consistently 2 – log removal achieved in the biomass with the higher SRT and solids concentration and a further 2 log removal achieved across the membrane (with a biofilm growth).

Table 1.0 following presents an outline of several different MBR suppliers with various pore sizes and associated pollutant removals.

Table 1.0: Membrane suppliers and associated pore size (Gander et al, 2000)

Microorganism rejection

Membrane	Pore size (µm)	Average log reduction[a]	Bacteria/virus[b]	Reference
Memtec[c]	0.2	ND	TC	[5]
PE[d]	0.1	4–6	Coliphage Qβ	[6]
PS[d]	0.5	5	TC	[7]
PS[d]	0.3	8[e]	TC	[8]
Memcor[c]	0.2	3.8	FC	[9]
Renovexx[c]	0.5–1.5	3.3	FC	[9]
Stork[f]	0.05–0.2	2.5	FC	[9]
Starcosa[f]	0.2	8[e]	TC	[9]
DOW[f]	0.2	<7	TC	[9]

[a] ND, non-detectable.
[b] TC, total coliforms; FC, faecal coliforms.
[c] Primary effluent.
[d] Activated sludge within MBR.
[e] Indicates zero bacteria in permeate.
[f] Secondary effluent.

5.2 FACTORS AFFECTING COLIPHAGE REMOVAL

Researchers (Farahbakhsh et al.) investigating the removal of virus and bacteriophage by membrane bioreactors have found removal is affected by the following factors including membrane pore size, water chemistry (pH and conductivity), bacteriophage feed concentrations, concentration of particulate matter in the feed, and the extent of membrane fouling.

5.3 FACTORS AFFECTING THE ENDOCRINE DISRUPTOR REMOVAL

The removal of Endocrine Disruptors such as pharmaceutical compounds will depend on their chemical state, as most compounds are relatively hydrophilic to ensure that they can be easily adsorbed by humans for medical purposes. Their biodegradation is slow because they have been designed to have long term effect on humans[1].

Membrane bioreactors (MBRs) are considered to show higher performance in terms of effluent water quality than conventional activated sludge processes. Urase et al., evaluated the degradation of three estrogens, two endocrine disruptors and ten pharmaceutical substances in an MBR plant. They found that removal processes were via biological degradation within the MBR process and deposition into the biofilm on the membrane surface. Generally the results from the Urase study showed greater removals across the membranes for hydrophobic compounds.

5.4 CONVENTIONAL TREATMENT

Studies have found that even in conventional wastewater treatment plants, as many as 10^3 CFU ml^{-1} resistant coliform bacteria were found in the effluent, this figure does not include much smaller viruses that would also be present[ii]. With the use of other disinfection methods such as chlorination, chlorine dioxide, ozone and UV radiation there are mutagenic and toxic by-products often accompanied by the treatment process. In addition, the presence of suspended solids and organic material in the wastewater can reduce the efficiency of disinfection.

5.4.1 CONVENTIONAL TREATMENT VERSUS MBR

When wastewater is treated to high standards, conventional methods employ the use of filtration for secondary treated effluent, ultraviolet radiation, or ozone treatment.

Conventional filtration generally involved passing secondary treated effluent through a deep bed filter such as a Sand filter to remove solids particles. When followed by UV disinfection, this form of treatment can achieve a significant reduction in pathogens.

Daughton and Ternes (1999) evaluated the removal of pharmaceutical compounds in conventional activated sludge plants and found removal of some compounds but little or no removal of other compounds. This may have been dependant on treatment system type rather than the ability to remove to toxicant. Brun et al (2006) proposed that removal is via several different pathways (physico chemical reactions, biofilm uptake etc.) and that different chemicals thus had different fates (and removals) within the treatment plants.

Table 2.0 is reproduced from the Queensland Water Recycling Guidelines and presents typical removal efficiencies for various process streams. As can be seen the Membrane filtration process is at least equal if not better at removal of the various pollutants than other processes.

Table 2.0 - Typical removal efficiencies for various process streams reproduced from the Queensland Water Recycling Guidelines.

Treatment	Indicative log reductions							
	E.coli	*Bacterial pathogens*	*Viruses*	*Phage*	*Giardia*	*Crypto*	*Clostridium perfringens*	*Helminths*
Primary Treatment	0-0.5	0-0.5	0-0.1	N/A	0.5-1.0	0-0.5	0-0.5	0-2.0
Secondary Treatment	1.0-3.0	1.0-3.0	0-2.0	0.5-2.5	0.5-1.5	0.5-1.0	0.5-1.0	0-2.0
Dual Media Filtration	0-1.0	0-1.0	0.5-3.0	1.0-4.0	1.0-3.0	1.5-2.5	0-1.0	2.0-3.0
Membrane Filtration	3.5 ->6.0	3.5->6.0	2.5->6.0	3->6.0	>6.0	>6.0	>6.0	>3.0
Lagoon Storage	1.0-5.0	1.0-5.0	1.0-4.0	1.0-4.0	3.0-4.0	1.0-3.5	N/A	1.5->3.0
Chlorination	2.0-6.0	2.0-6.0	1.0-3.0	0-2.5	0.5-1.5	0-0.5	1.0-2.0	0-1.0
Ozonation	2.0-6.0	2.0-6.0	3.0-6.0	2.0-6.0	N/A	N/A	0-0.5	N/A
UV Light	2.0->4.0	2.0->4.0	>1.0 adenovirus >3.0 enterovirus, hepatitis A	3.0-6.0	>3.0	>3.0	N/A	N/A
Wetlands – surface flow	1.5-2.5	1.0	N/A	1.5-2.0	0.5-1.5	0.5-1.0	1.5	0-2.0
Wetlands – subsurface flow	0.5-3.0	1.0-3.0	N/A	1.5-2.0	1.5-2.0	0.5-1.0	1.0-3.0	N/A

Source: Draft National Guidelines for Water Recycling (NRMMC & EPHC 2005). These are all average or typical values: actual reductions depend on specific features of each process including detention times, pore size, filter depths, disinfectant contact time etc. Other emerging technologies can also achieve high levels of log reduction, but this will generally require validation. Each treatment system needs validation under its specific operating conditions.

N/A = not available.

Table 3.0 presents results from a study undertaken by Oota et al., (2005) comparing the removal efficiencies of the conventional activated sludge (CAS) and MBR processes for Coliphage removal. In all cases the MBR outperformed the CAS process. However it must be noted that there was no detail presented as to the disinfection specifications for the CAS plant and as such a definitive statement could not be made from the results.

Table 3.0: Removal of Coliphage (PFU/100mL)

	Primary effluent			Effluent		
	mean	max.	min.	mean	max.	min.
CAS	3.6×10^5	1.1×10^6	1.5×10^5	2.7×10^2	4.9×10^2	40
MBR	3.6×10^5	4.9×10^5	1.2×10^5	1	5	0

6 FUTURE WORK

The following future work requirements have been evaluated using the above information gathered from various sources discussing both conventional treatment systems and MBR plants for virus removal and degradation of endocrine disruptors.

Given the physical nature of removal within the MBR process it is felt that F – Specific Bacteriophage tests are appropriate given the costs involved in more specific virus testing. This will be combined where possible with particle size counts from the MBR permeate to evaluate the size of particles discharged from the process. This will allow an evaluation of both the prospective removal techniques of viruses and an evaluation of which viruses may or may not be removed.

The following outlines the future works required to effectively evaluate and compare both conventional plants and MBR plants for virus and endocrine disruptor removal. Some of this work will be dependant on the availability of funding to undertake the virus (or indicator) and endocrine disruptor testing.

- Conventional Plants
    - Find and assess plants with Resource Consent requirements for Virus or phage testing and evaluate existing results.
    - Assess the effectiveness of these plants and indicate where filtration systems are not included to evaluate the potential shielding effects.
    - Virus testing of existing plants.
    - Endocrine disruptor testing of existing plants.
    - Review potential of uptake in Biomass.
    - Discuss research with suppliers to further evaluate background information.

- MBR
    - Assess particle size distribution of effluent and compare with known human pathogen virus sizes.
    - Virus testing of existing plants.
    - EDC testing of existing plants.
    - Review potential of uptake in Biomass.
    - Discuss research with suppliers to further evaluate background information.

7 CONCLUSIONS

Most of the research received states that the MBR process is effective at removal of viruses from effluent streams. The mechanisms of this are unclear and require further research. There are indications that significant removal of viruses occurs within the biomass, and that the biofilm growth on the membranes results in a barrier to viruses by reducing the effective pore size of the membranes.

Endocrine disruptor removal processes seem to be enhanced within the MBR process, however the removal mechanisms are also unclear. Little information is currently available as to the removal processes for endocrine disruptors and more research is required to evaluate this.

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