

WATER TRANSFORMED:

SUSTAINABLE WATER SOLUTIONS FOR CLIMATE CHANGE ADAPTATION

MODULE C: INTEGRATED WATER RESOURCE PLANNING AND MANAGEMENT

This online textbook provides free access to a comprehensive education and training package that brings together the knowledge of how countries, specifically Australia, can adapt to climate change. This resource has been developed through support from the Federal Government's Department of Climate Change's Climate Change Adaptation Professional Skills program.

CHAPTER 6: URBAN AND INDUSTRIAL WATER TREATMENT, REUSE AND RECYCLING.

LECTURE 6.2: INDUSTRIAL WATER REUSE, TREATMENT AND RECYCLING TECHNOLOGIES.

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Urban and Industrial Water Treatment, Reuse and Recycling to Adapt to Climate Change.

Lecture 6.2: Industrial Water Reuse and Recycling – Wastewater Treatment and Recycling Technologies.

Educational Aim

This lecture firstly overviews a number of companies that have achieved at least 50 per cent potable water savings through an integrated approach to water efficiency, water treatment and reuse. In lectures 2.1-2.4, 3.1-3.3 and 4.1-4.3 we showed that there was a strong business case for using water more efficiently. Here we provide examples which show that there is also a business case for treating and reusing water onsite to further reduce freshwater and trade waste costs. To help business's identify opportunities in this area, the main purpose of this lecture is to provide an overview of the different water treatment technologies. As earlier lectures have shown, there is significant potential to increase the level of water reuse and recycling in Australia. But to achieve this, greater understanding and awareness is needed across business and industry. This lecture, and its further reading resources, seek to provide such a guide.

Key Learning Points

1. There are now many examples of business using combinations of wastewater treatment technologies to enable significant quantities of water to be recycled and reused. When this is combined with water efficiency measures, businesses can significantly reduce their reliance on potable freshwater. For instance, Inghams Enterprises have reduced mains water usage by 70% achieving savings of 545 megalitres per annum.¹ Inghams Enterprises have achieved these remarkable results by installing an Advanced Water Treatment Plant which uses a combination of physical, biological and chemical processes to treat the water, including biological nutrient removal, membrane separation techniques, ultraviolet radiation and chlorination.² These processes provide a multi-barrier approach which has enabled Inghams Enterprises to comply with Australian water recycling and drinking water guidelines.³
2. Achieving the desired level of water quality from wastewater will generally require multiple stages of treatment as in the Ingham Enterprises case. The efficiency and effectiveness of the chosen method can be improved by choosing an appropriate pre-treatment. Regular system maintenance is essential for maintaining consistent water quality. Another key consideration that

¹ DEWHA (2010) *Prime Minister's Water Award Factsheet*. DEWHA Water Efficiency Opportunities Program at <http://www.environment.gov.au/water/publications/urban/pubs/pm-waterwise-award-winners.pdf> Accessed 26 May 2010.

² Ibid.

³ DEWHA (2010) *Prime Minister's Water Award Finalists – Inghams Enterprises*. DEWHA Water Efficiency Opportunities Program at <http://www.environment.gov.au/water/publications/urban/pubs/pm-waterwise-award-finalists.pdf> accessed May 20 2010 National Health and Medical Research Council (2004) *Australian Drinking Water Guidelines*. Commonwealth Government. <http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm> Accessed 21 April 2010. Natural Resource Management Ministerial Council (NRMCM), Environment Protection and Heritage Council (EPHC), Australian Health Ministers Conference (AHMC) (2006) *National Guidelines for Water Recycling: Managing Health and Environmental Risks*. NRMCM, EPHC, AHMC. <http://www.ephc.gov.au/taxonomy/term/39> accessed March 3 2010.

will determine the impact a system's cost and complexity is how to manage the waste that will be produced.⁴

3. The treatment method chosen for a system must deliver water quality appropriate for the end uses. The requirements of each location and end use application, together with the water and wastewater characteristics, will have specific design needs.

4. There are broadly three main methods of wastewater treatment – physical, biological and chemical. Within these 3 areas there are 6 different types of water or wastewater treatment technologies and approaches commonly used; flotation and basic filtration (physical), membrane filtration (physical), membrane bioreactor (physical and biological), biological treatment (biological), ion exchange (chemical) and disinfection (chemical).⁵

5. Flotation and basic filtration: Flotation is an effective means of removing grease and oil, together with some suspended solids, from wastewater. Larger solids can be removed using basic filtration. These can be applied either as a pre-treatment, improving the efficiency of subsequent treatment processes, or to meet waste standards prior to discharge into sewers.

6. Membrane filtration: this involves forcing pressurised water or wastewater through a semi-permeable membrane. It is an effective means of removing solids and dissolved salts. Membrane technology has made some major advances in recent years and now has broad application. Membranes are available in four main types: microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO) and nanofiltration (NF).⁶ The latter two are particularly effective at removing salts, dissolved solids, enhanced organics and pathogen.

7. Membrane bioreactors (MBRs): these are a proven option in the treatment of wastewater that use a single tank combination of an activated sludge process and either micro or ultra-filtration. A key advantage of this technology is the ease of upgrade or retro-fit to existing older treatment plants.⁷ MBRs have application for both domestic wastewater and municipal and industrial waste treatment. When applied to the former, MBR output is of sufficient quality to be released to surface, brackish or coastal waterways or used in urban irrigation. Applied to the latter, membrane suspension combined with a suspended-growth bioreactor is effective.

8. Biological treatment: The biological treatment processes use micro-organisms to treat the waste water using similar process that occurs naturally but under more controlled conditions. There are three types of biological treatment approaches, anaerobic (for instance upflow anaerobic sludge bed reactors, suspended growth reactors, fixed film reactors), aerobic (for instance activated sludge process, sequential batch reactor, fixed film reactors) and mixed aerobic/anaerobic systems (for instance constructed wetlands).

- Anaerobic: Anaerobic biological treatment usually involves anaerobic digestion which breaks down the biodegradable component of the waste to produce biogas and soil improver. The biogas can be used to generate electricity and heat and thus reduce greenhouse gas emissions.

⁴ UN ESCWA (2003) *Waste-Water Treatment Technologies – A General Review*. UN ESCWA. <http://www.escwa.un.org/information/publications/edit/upload/sdpc-03-6.pdf> Accessed 10 May 2010.

⁵ Ibid

⁶ Sydney Water (2009) *Water Treatment Options*. Sydney Water. Available at <http://www.sydneywater.com.au/Publications/FactSheets/WaterTreatmentOptions.pdf> Accessed 15 May 2010

⁷ Judd, S. (2006) *Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment*, Elsevier, Oxford. UK.

- **Aerobic Treatment:** In aerobic systems air is pumped through the wastewater in biological reactors. Aerobic biological systems are mostly used for treating low concentration waste (typically where the BOD is less than 1000mg/L). In these systems, about 50% of biodegradable organic matter is converted to sludge, which must be disposed of. The rest is converted to water and air. Aerobic systems are used in the food manufacturing industry and to treat municipal wastewater.
- **Combined Anaerobic/Aerobic Treatment Systems:** Another important biological treatment approach is the use of constructed wetlands. Wetlands achieve biological treatment through both natural anaerobic and aerobic processes.⁸ Constructed wetlands will be covered further in the following lectures on stormwater management, harvesting and reuse (lecture 6.3) and urban water sensitive design (Lecture 7.1). Finally, some biological treatment systems incorporate both anaerobic digestion and the aerobic process of composting. This can take the form of a full anaerobic digestion phase, followed by the maturation (composting) of the digestate.

9. **Ion exchange:** widely applied in the treatment of water for refined end-uses, including the semi-conductor and pharmaceutical industries (which require ultra-pure water), and boiler-feed water. It is used to remove trace contaminants.

10. **Disinfection:** this includes processes such as chlorination, and the use of ozone and ultra violet light, and is effective at killing pathogens such as viruses, bacteria and protozoa. It is usually applied as a secondary treatment in situations where there is a risk that treated water will come into contact with the human population.

These water treatment technologies used in combination can help industry comply with the Australian guidelines for recycling of water.⁹

Brief Background Reading

In lectures 2.1-2.4, 3.1-3.3 and 4.1-4.3 we showed that there was a strong business case for using water more efficiently. Here we provide examples showing that there is also great potential for businesses to treat and reuse water to further reduce their freshwater and trade waste costs. Ingham Enterprises is not the only company showing the potential for business from investing in water treatment/reuse and stormwater harvest and reuse opportunities. When companies invest in water efficiency opportunities in combination with water treatment and reuse opportunities the potable water savings can be significant.

- At Port Kembla, on the NSW coast, Sydney Water's largest industrial water recycling development generates a saving of approximately 17% of Wollongong's daily water use. 20 ML of recycled water per day and used by the Port Kembla Coal Terminal and BlueScope Steel. The wastewater undergoes a multi-stage treatment to get it to tertiary level, after which microfiltration and reverse osmosis are applied to deliver water appropriate to BlueScope's particular requirements. Any residual water undergoes

⁸ Greenway, M. (2003) *The role of wetlands in effluent treatment and reuse schemes*. CD-ROM, Water Recycling Australia, 2nd National Conference 1-3 September, 2003 Brisbane. Australian Water Association, Sydney

⁹ Natural Resource Management Ministerial Council (NRMMC), Environment Protection and Heritage Council (EPHC), Australian Health Ministers Conference (AHMC) (2006) *National Guidelines for Water Recycling: Managing Health and Environmental Risks*. NRMMC, EPHC, AHMC. <http://www.ephc.gov.au/taxonomy/term/39> accessed March 3 2010

additional treatment (ultraviolet light disinfection) before being discharged offshore via an outfall.¹⁰

- At their Cartonboard Mill in Petrie, Amcor Australia has achieved an annual freshwater saving of more than 1000 ML. Formerly in the top 10 water users in the area, this saving of over 4 ML per day, has been achieved via a 90% reduction in the use of drinking water in the manufacturing process, which now uses treated and purified recycled water instead.¹¹
- With 55 projects focussing on saving water, Coca Cola Amatil is amongst the most efficient Coke bottlers internationally. The projects range across water treatment, recycling and reuse and stormwater harvesting, and have positioned the company at the forefront of such efforts within the global beverage industry.¹²
- Diageo Australia Limited, an international beverage manufacturer, has achieved a 43% water saving at its Huntingwood site. This annual saving of 55.5 ML has been realised through a combination of improved management practices and innovative water saving measures. Efficiency initiatives have enabled significant freshwater savings, but more than 50% of the savings have been achieved through optimisation of the reverse osmosis recovery process.¹³
- The Rosssdale Golf Club has achieved an annual reduction of mains water usage of 35 ML. This cut, a reduction of 56%, has been achieved through a combination of stormwater harvesting and construction of storage dams. The club has a 43 ML storage capacity, comprised in part of an aquifer storage and recovery facility, and a permit to harvest stormwater from a barrel drain adjacent to the property.¹⁴

In each of these examples these businesses have chosen specific water treatment technologies to enable their wastewaters to be treated to standards needed for that water to be reused. Water treatment is needed in many industries whether they reuse their wastewater or not as their wastewaters contain a significant number of pollutants that need to be treated before that water is re-released into natural systems. For instance in the following industries the following pollutants tend to be common –

- Iron production - Ammonia and cyanide, along with other chemicals, contaminate water used for cooling in the blast furnace production of iron. Water used in coke production (from coal), for separation of by-products, can contain contaminants including gasification products (e.g. naphthalene, benzene, cyanide, ammonia, phenols and cresols) as well as polycyclic aromatic hydrocarbons (PAH).
- Steel production – The hot and cold mechanical transformations involved in converting iron (or steel) into wire and other products, use water as a lubricant and coolant. The final stage of treatment (prior to use in manufacturing) involves pickling with strong mineral acid (usually hydrochloric and sulphuric). These two processes produce contaminants including hydraulic (soluble) oils, particulate solids, tallow, acidic rinse water and waste acid.

¹⁰ Bluescope Steel (2006) *Community, Safety and Environment Report – Water Case Studies*. Bluescope Steel at http://csereport2006.bluescopesteel.com/environment/water_case_studies.html#less accessed May 3 2010

¹¹ Amcor (undated) *Environmental Sustainability – Water Use*. Amcor at

http://www.amcor.com/about_us/sustainability_amcor/environmental_sustainability/64347357.html accessed May 3 2010

¹² DEWHA (2010) *Prime Minister's Water Award Finalists*. DEWHA Water Efficiency Opportunities Program at <http://www.environment.gov.au/water/publications/urban/pubs/pm-waterwise-award-finalists.pdf> accessed May 20 2010

¹³ Ibid.

¹⁴ Ibid.

- Mines and quarries - Slurries of rock particles are the main contaminants associated with quarries and mines, and result from the rock washing and grading process and rainfall run-off from haul roads and other associated exposed surfaces. Particulate haematite and surfactants contaminate wastewater from some separation operations (e.g. coal from native rock), while oils and hydraulic oils are commonplace. Metal mine and ore recovery operation wastewaters are contaminated with minerals found in the native rock, and can include undesirable materials left over after extraction of the desired materials. In the case of metal mines, these undesirable materials can include zinc and arsenic.
- Food industry - Wastewater resulting from agricultural and food production tends to have high concentrations of suspended solids and has high biochemical oxygen demand (BOD). Variation in BOD and pH in fruit and vegetable and meat product effluent, as well as seasonal factors, make it difficult to predict the contaminants in food wastewater. Food processing wastes are generally high in organic material associated with cooking. These can include not only high levels of fats and oils, but also flavourings, salt, colours, acids and alkali. Wastewater from the slaughter and processing of animals contains strong organic contaminants (e.g. from blood and gut content), and can have considerable concentrations of growth hormones, antibiotics and pesticides. Wool processing produces wastewater that contains significant levels of insecticides from residue from the fleeces.

Clearly, industrial wastewaters need to be treated whether the water is going to be reused or released back into the environment. Sydney Water and many other water authorities have produced significant freely available information (see further reading) for commercial customers regarding treatment of trade waste (wastewater). Hence this lecture does not focus on this topic as it is well covered already. The rest of this lecture focuses on water treatment technologies which enable businesses to reuse and recycled water to reduce their dependence on mains water. To achieve this, water treatment is required to reduce the level of pollutants. Sydney Water has produced the following diagram that communicates both the main pollutants that need to be treated and which water treatment technologies can be used for such purposes. The rest of this lecture focuses on the main water treatment technological options as listed by Sydney Water here. (See figure 6.2.1)

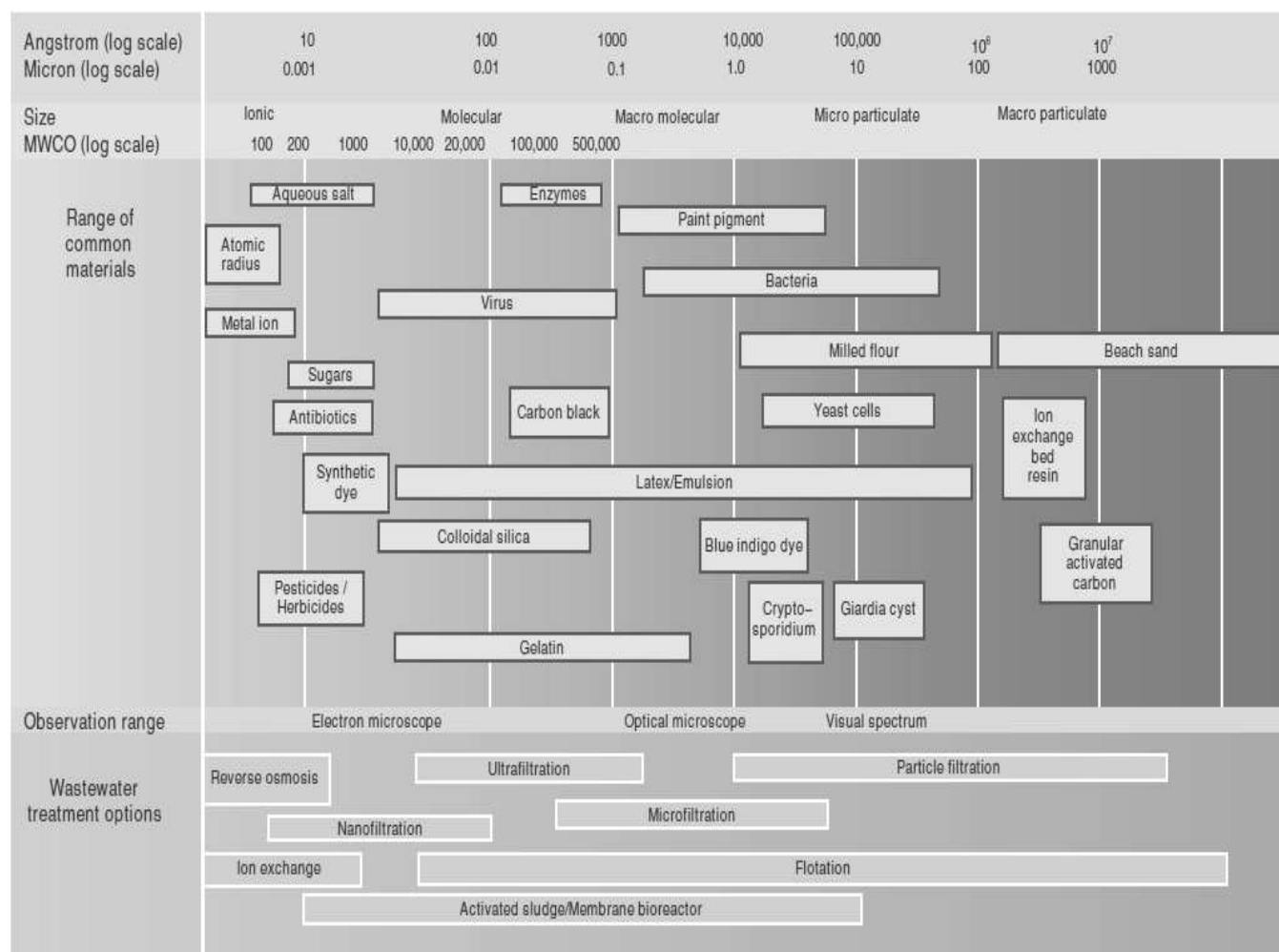


Figure 6.2.1 Treatment options for water reuse.

(Source: Sydney Water¹⁵, 2009)

The following provides an overview of the main types of wastewater treatment technologies listed in the above Sydney Water diagram.

Flotation and Basic Filtration

Flotation is an effective means of removing grease and oil, together with some suspended solids, from wastewater. Larger solids can be removed using basic filtration. These can be applied either as a pre-treatment, improving the efficiency of subsequent treatment processes, or to meet waste standards prior to discharge into sewers.

The most common flotation process is dissolved air flotation (DAF).¹⁶ Dissolved air flotation (DAF) is a water treatment process that clarifies wastewaters (or other waters) by the removal of suspended matter such as oil or solids. To do this, air is dissolved under pressure in the wastewater then released into a flotation tank at atmospheric pressure. Suspended matter adheres to the resulting air bubbles, floats to the surface, and is collected via skimming. Thus, DAF uses fine air bubbles to separate liquid particles and light suspended solids (but not

¹⁵ Sydney Water (2009) *Water Treatment Options*. Sydney Water. Available at <http://www.sydneywater.com.au/Publications/FactSheets/WaterTreatmentOptions.pdf> Accessed 15 May 2010

¹⁶ Ibid.

dissolved contaminants) from wastewater. These particles and solids are floated to the surface via the bubbles, where they are skimmed from the surface in the form of sludge (4 – 6% solids). The efficiency of this process can be enhanced through the addition of flocculants and coagulants, which bind suspended particles into larger masses, though this may require some adjustment of the wastewater's pH. It may necessary to use a balance tank so this process is not disturbed by the inflow of wastewater. With little operator input necessary, DAF is a relatively easy process that is cheap to run. One of the main applications of DAF is in the treatment of industrial wastewater effluent from industries including paper manufacturing, oil refining and natural gas processing and general water treatment. Its uses also include grease and oil removal from commercial kitchen wastewater and various applications in the paper and pulp industry.

Membrane Filtration

Membrane filtration is a fast growing technology that can produce high quality effluent, in a wide range of situations. Membranes can provide consistent high quality water free of nearly all target contaminants, regardless of influent quality.¹⁷ Membranes remove solids and dissolved salts from water and wastewater by forcing them through a semi-permeable membrane, generally under pressure. Concentrated waste is captured on the membrane surface. There are four major types of membranes:

1. Microfiltration (MF) - MF removes contaminants by passing fluid (liquid or gas) through a membrane with pores of 0.1 to 10 microns. Pressure can be used but, unlike nanofiltration and reverse osmosis, is not essential. The membranes can be composed of fibers ranging from hollow and tubular, to track etched or spiral wound, and can be configured in either a submerged or pressure vessel arrangement. They are effective in filtering algae, large bacteria, sediment and particles, while allowing water, small colloids, dissolved organic matter, viruses and monovalent ions (Na⁺ & Cl⁻) to pass through.

2. Ultrafiltration (UF) - UF employs hydrostatic pressure to force liquid onto a semipermeable membrane. The membrane allows water and solutes of low molecular weight to pass, while suspended solids and high molecular weight solutes are held back. An effective means of purifying and concentrating macromolecular solutions, UF is used to recycle flow and add value to later products in industries including food and beverage manufacturing, wastewater treatment, and chemical and pharmaceutical processing. By employing solution flow pressurisation, UF is widely applied in continuous systems for the purification, separation and concentration of target macromolecules. Targeting is effected by selecting a membrane with the appropriate molecular weight cut-off (MWCO).

3. Reverse osmosis (RO) - RO involves the application of pressure to a fluid column in excess of its osmotic pressure. In a situation where two fluids containing differing concentrations of dissolved solids are separated by a semi-permeable membrane, this results in the passage of fluids through the membrane but the retention of dissolved solids in the column to which the pressure is applied. As an effective means of reducing the salt content of water, RO's main applications are the production of drinking water, ultra pure water and boiler feed water. It also has application in the dairy, food and galvanic industries.

¹⁷ Ibid.

4. Nanofiltration (NF) - NF employs a combination of pressure and membranes to effect separations based on molecule size. As such it has many similarities with reverse osmosis (RO). Its predominant application is in the removal organic materials (e.g. multivalent ions and micro pollutants). However, whereas RO is 98-99% effective (at 200psi) in the removal of monovalent ions, NF ranges between 50-90% effectiveness. The range for NF varies according to the membrane's material and manufacture. Hence, a range of NF membranes exist, each with a specific application. NF's main application is in drinking water purification, particularly decolouring, softening and removal of micro-pollutants. It also has industrial applications, for example laundry wastewater recycling, pesticide removal from groundwater and the removal of heavy metals from wastewater. In general, NF and RO membranes are effective in the removal of dissolved salts, while MF and UF membranes are effective in the removal of dissolved solids. The smaller the pore size (MF largest - RO smallest) of the membrane, the greater the operating pressure required. For example, MF membranes having the largest pore size can be effective with <200 kPa, whereas RO membranes with the smallest pore size require >1,000 kPa to be effective. Examples of membrane treatment, according to Sydney Water¹⁸, include:

- salt removal from brackish or saline solutions – RO
- colour removal in the textile industry – UF/NF/RO
- pulp and paper water recovery – UF
- oily wastewater treatment – UF
- laundry effluent treatment – UF/NF/RO
- boiler feed water treatment – UF/RO
- landfill leachate – UF/RO.¹⁹

Whilst membranes are very effective water treatment technologies, membranes can become fouled from suspended solids or covered in scale and salts, if not properly operated. The risk can be reduced by:

- selecting the appropriate membrane
- maintaining proper operating conditions (including rate of recovery)
- cleaning membranes regularly.
- pre-treating waste (including pH control, dosing with anti-scalant and pre-screening as outlined in table 6.1.1) The pre-treatment of feed water for nano-filtration or reverse osmosis installations greatly influences the performance of the installation. The required form of pre-treatment depends on the feed water quality. The purpose of pre-treatment is reducing the organic matter content and the amount of bacteria, as well as lowering the MFI. The organic matter content and the amounts of bacteria should be as low as possible to prevent the so-called bio-fouling of membranes. The application of a pre-treatment has several benefits:
 - Membranes have a longer life-span when pre-treatment is performed

¹⁸ Ibid.

¹⁹ Ibid.

- The production time of the installation is extended
- The management tasks become simpler
- The employment costs are lower

Table 6.1.1 Pre-treatment options to prevent fouling of membranes

Pre-treatment	CaCO ₃	SO ₄	SiO ₂	MFI	Fe	Al	Bacteria	Organic matter
Acid dosage	HE				E			
Anti-scalant	E	HE						
Softening and ion exchange	HE	HE						
Preventive cleansing	E		E	E	E	E	E	HE
Adjusting of process parameters		E	HE					
Quick filtration			E	E	E	E		
Flocculation			E	HE	E	E		

HE = highly effective and E = effective pre-treatment (Source: Lenntech²⁰, undated)

Finally, membrane processes are generally energy intensive, but are becoming more energy efficient. It is important to note that their energy usage compares well to desalination. Desalination needs 3.5 kWh of electricity to produce one kilolitre of water, compared to about 2 kWh for other wastewater treatment options.²¹ The additional energy demands may be offset by a reduced need for chemical treatment, a more streamlined treatment process, and higher quality treated water that can be used in a wider range of applications.

Membrane Bioreactors

Membrane bioreactors (MBRs) combine the use of biological processes and membrane technology to treat wastewater. Within one process unit, a high standard of treatment is achieved, replacing the conventional arrangement of aeration tank, settling tank and filtration that generally produces what is termed as a tertiary standard effluent. The dependence on disinfection is also reduced, since the membranes with pore openings, generally in the 0.1-0.5mm range, trap a significant proportion of pathogenic organisms. Membrane bioreactors (MBR), with their combination of membrane separation and suspended growth bioreactor, are now widely used in the food processing industry and for municipal and industrial wastewater treatment.²² Innovations in membranes and significant cost reductions have enabled this.²³ The process in MBR combines

²⁰ Lenntech Water Treatment Solutions (undated) *Nano filtration and Reverse Osmosis Membrane technology*. Lenntech Water Treatment Solutions at <http://www.lenntech.com/nanofiltration-and-rosmosis.htm> accessed 29 May 2010

²¹ Sydney Water (2009) *Water Treatment Options*. Sydney Water. Available at <http://www.sydneywater.com.au/Publications/FactSheets/WaterTreatmentOptions.pdf> Accessed 15 May 2010

²² Ibid

²³ Judd, S. (2006) *The MBR book Principles and applications of membrane bioreactors in water and wastewater treatment*, Elsevier, Oxford.

in a single tank the activated sludge process with membrane filtration (either MF or UF). In general, MBR applications for wastewater treatment can be classified into four groups²⁴, namely:

1. Extractive membrane reactors: Extractive membrane bioreactors (EMBRs) improve the effectiveness of biological treatment of wastewater by taking advantage of the membrane's ability to achieve a high degree of separation while allowing transport of components from one phase to another. This separation enables favourable conditions for biological degradation of wastewater pollutants to be achieved and maintained in the bioreactor. This has proven to be very effective at treating toxic organic pollutants in wastewater such as chloro-ethanes, chloro-benzenes, chloro-anilines, and toluene.²⁵

2. Bubble-less aeration membrane bioreactors: The process efficiency of a conventional aerobic wastewater treatment, like an activated sludge process unit, is proportional to the availability of air. Typically, in an activated sludge process, 80-90% of the oxygen diffused as air is vented to the atmosphere. However,

The membrane aeration bioreactor (MABR) process use gas permeable membranes to directly supply high purity oxygen without bubble formation to a biofilm. Here the bubble free aeration is achieved by placing a synthetic polymer membrane between a gas phase and a liquid phase. This membrane is used to transfer large quantity of air/oxygen into the wastewater. As the gas is practically diffuse through the membrane, very high air transfer rate is attained. The membranes are generally configured in either a plate-and-frame or hollow fibre module. However, current research has focussed on the hollow fibre arrangement with gas on the lumen-side and wastewater on the shell-side. The hollow fibre modules are preferred since the membrane provides a high surface area for oxygen transfer while occupying a small volume within the reactor. Here the membrane also acts as a support medium for the biofilm formation, which reduces the potential for bubble formation and air transfer rate.²⁶

3. Recycle membrane bioreactors (RMB): RMB's are utilised essentially in two basic configurations for industrial applications, beaker type and tubular.

- In the beaker type system, the wastewater and biocatalyst is placed in a beaker where they react. Then a U shaped bundle of membranes are dipped into the beaker and the membranes filter product.
- Tubular configurations are preferred in large-scale industrial applications. This type of bioreactor is excellent for industrial scale removal of aromatic pollutants and pesticides.²⁷

4. Membrane separation reactors: Membrane Separation Reactors (MSR) solve a number of problems with the traditional activated sludge process, which historically has been the most widely used aerobic wastewater treatment system to treat wastewater. While the activated sludge process is reliable, the quality of the final effluent from such a process is dependent on the hydrodynamic conditions in the sedimentation tank and the settling characteristics of the sludge. As a result, large sedimentation tanks and close control of the biological treatment unit is required

²⁴ Visvanathan, C., Aim, R. (2010) *Membrane Bioreactor Applications in Wastewater Treatment*.

<http://www.faculty.ait.ac.th/visu/Prof%20Visu's%20CV/chapters%20in%20Books/11/MBR.%20text1.pdf> accessed 11 May 2010.

²⁵ Stephenson, T. Judd, S. Jefferson, B. Brindle, K (2006) *Membrane Bioreactors for WasteWater Treatment*. IWA Publishing. London.

²⁶ Visvanathan, C., Aim, R. (2010) *Membrane Bioreactor Applications in Wastewater Treatment*.

<http://www.faculty.ait.ac.th/visu/Prof%20Visu's%20CV/chapters%20in%20Books/11/MBR.%20text1.pdf> accessed 11 May 2010.

²⁷ Judd, S. (2006) *The MBR book Principles and applications of membrane bioreactors in water and wastewater treatment*, Elsevier, Oxford.

to obtain adequate solid/liquid separation over many hours. The use of MSRs, which involve the use of membrane separation (micro or ultra filtration) techniques for bio-solid separation in a conventional activated sludge process, can overcome these disadvantages in the traditional activated sludge process. The other major advantages of MSRs are:

- They occupy a relatively small amount of space and yet can handle large variations in biological oxygen demand in incoming wastewater, while producing a consistent quality of treated water.
- Suspended solids are totally eliminated through the use of membrane separation, hence the sludge's ability to settle does not affect the quality of the treated effluent, making it easy to run.
- They do not need sedimentation nor any post-treatment equipment to achieve required water quality levels. This saves space and provides operational cost savings.
- Removes bacteria and viruses. The membrane provides a barrier to chlorine resistant pathogens, such as cryptosporidium, which expands opportunities for reuse. Sludge production can be minimised.
- Since all the process equipments can be tightly closed no odour dispersion can occur.
- MBR tanks are modular, so the treatment plant can easily be expanded.

MBR does however have some disadvantages such as high capital and operating costs compared to traditional biological treatment processes, but the gap is narrowing. The other main drawback with MBR methods is fouling of the membrane.²⁸ Frequent membrane cleaning and replacement is therefore required, increasing significantly the operating costs. Many anti-fouling strategies can be applied to MBR applications. They include using intermittent permeation, where the filtration is stopped regularly for a couple of minutes before being resumed. Membrane backwashing is another common anti-fouling technique, where water is pumped back to the membrane, and flow through the pores to the feed channel, dislodging internal and external foulants.

Biological Systems

Biological systems for wastewater treatment are relatively simple, cost effective and energy efficient. Biological systems don't require any chemicals and produce less waste. Anaerobic systems are cheap to operate and can produce valuable biogas for energy recovery. Biological systems can be used in many industrial, municipal, commercial and residential building applications. Biological processes use bacteria to reduce the organic matter in wastewater. They also remove ammonia from wastewater by firstly removing ammonia by transforming it into nitrates (nitrification) and then by removing the nitrates (denitrification). Biological processes can be used when the proportion of biodegradable organic matter is more than 40% of the total organic matter in the wastewater. This is measured by the biological oxygen demand (BOD)/chemical oxygen demand (COD) ratio.

As discussed in the key learning points, biological treatment processes may be aerobic or anaerobic or a mixture of both. Processes used in aerobic systems include:

²⁸ Judd, S. (2006) *The MBR book Principles and applications of membrane bioreactors in water and wastewater treatment*, Elsevier, Oxford

- Activated sludge process (ASP): Activated sludge is a biochemical process for treating sewage and industrial wastewater that uses air (or oxygen) and microorganisms to biologically oxidise organic pollutants, producing a waste sludge containing the oxidised material.
- Sequential batch reactors (SBR): Sequencing batch reactors (SBR) are industrial processing tanks for the treatment of wastewater. SBR reactors treat wastewater such as sewage or output from anaerobic digesters or mechanical biological treatment facilities. Oxygen is bubbled through the wastewater to reduce biochemical oxygen demand (BOD) and chemical oxygen demand (COD) to make suitable for discharge into the sewerage system or for use on land.

Anaerobic systems operate in the absence of oxygen. These systems are used for highly concentrated waste, such as breweries, or where sugar and carbohydrate rich wastewater needs treatment. About 10% of organic matter remains as sludge. There are many different types of anaerobic systems, hence we cannot cover them all. One of the most commonly used is the up flow anaerobic sludge bed reactors. This technique uses an anaerobic process whilst forming a blanket of granular sludge which suspends in the tank. Wastewater flows upwards through the blanket and is processed (degraded) by the anaerobic microorganisms. The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants. The blanket begins to reach maturity at around three months. Small sludge granules begin to form whose surface area is covered in aggregations of bacteria. In the absence of any support matrix, the flow conditions create a selective environment in which only those microorganisms, capable of attaching to each other, survive and proliferate. Eventually the aggregates form into dense compact biofilms referred to as 'granules'. Biogas with a high concentration of methane is produced as a by-product, and this may be captured and used as an energy source, to generate electricity for export or to cover its own running power or a combination of both.

Finally, other biological systems such as constructed wetlands can also assist that have naturally both anaerobic and aerobic processes.²⁹ Leading companies are building their own constructed wetlands for wastewater treatment. Constructed wetlands combine physical, chemical, and biological processes to remove contaminants from wastewater. An understanding of these processes is fundamental not only to designing wetland systems but to understanding the fate of chemicals once they have entered the wetland. This will be discussed in detail in lecture 7.1 on urban water sensitive design.

It is important to note that there are some limitations to biological wastewater treatment systems such as they cannot be used in heavy industry where metals, paints and chemical pollutants, which are not biodegradable, are common. Also biological systems can only operate effectively within certain temperature, pH and wastewater quality ranges. If the biological system becomes seriously out of balance it can be difficult to re-establish. Biological systems can generate odours if they aren't properly designed or operated. This may be more prevalent with anaerobic systems. Biological systems can require a lot of space, but this can be reduced by technologies such as the sequential batch reactor.

Ion Exchange

²⁹ Greenway, M. (2003) *The role of wetlands in effluent treatment and reuse schemes*. CD-ROM, Water Recycling Australia, 2nd National Conference 1-3 September, 2003 Brisbane. Australian Water Association, Sydney

Ion exchangers consist of a specially made resin which removes unwanted ions dissolved in wastewater and replaces them with desirable ions that are held in the resin.³⁰ Ion exchange resins can be used to remove or recover water hardness (calcium and magnesium ions), alkalinity, metals, nitrates, sulphates, and even ammonia.³¹ Ion exchangers are very useful to remove trace contaminants in water for high-water quality applications such as ultra pure water for the pharmaceutical and semi-conductor industries.

It is important to understand how an ion exchange works so as to inform your decisions regarding the best approach to water treatment. The ions exchanged, in an 'ion exchanger', are positively charged atoms (metals, magnesium, calcium) and small particles known as 'cations' or negative atoms or particles known as 'anions'. To remove and recover positively charged ions a cationic exchanger can be used and likewise an anionic exchanger to remove and recover negatively charged ions. Ion exchangers have a resin which exchanges positive and negative ions with the solution, with the unwanted ions removed by being captured and attached to the resin. For instance, a cation exchange unit removes positively charged ions like Ca^{++} (calcium ions are positively charged) and Mg^{++} (magnesium ions are positively charged) to help remove hardness and soften water. For instance, an anionic exchange unit often has a resin that exchanges chloride or hydroxide for the anions (the negatively charged atoms) that they remove such as nitrates and sulphates.³²

Alternatively mixed bed resin exchangers can be used to remove and replace both positive and negative ions. These simply have both types of resin to attract and remove positive and negative ions. When water to be treated passes through the ion exchange unit, ions in the water are attracted by either a positive or a negative charge to the ions in the resin bed. Since the ions from the water are held more tightly by the resins than they were held in the water, they are removed from the water in the exchange process.

The effectiveness of ion exchange resins reduces over time as the resin absorbs cations or anions. Hence periodically they need to be regenerated or replaced. Pre-treating water with membrane filtration will greatly reduce the frequency of regeneration. Finally, it is important to note that the waste accumulated in the resins from this process needs to be disposed of appropriately.

Disinfection

As discussed in lecture 5.3, disinfection is used to kill pathogens such as bacteria, viruses and protozoa where there is a risk of close human contact with treated wastewater. It is generally used as a secondary treatment. Disinfection processes include chlorination, ultra violet light and ozone.³³ Chlorine is well proven and effectively kills most pathogens but not cryptosporidium. Chlorine provides residual disinfection. UV and ozone can be produced on site, which avoids the need to handle dangerous chemicals, but uses a lot of energy. UV and ozone don't produce residual chemicals, which can make them more appropriate if you are discharging wastewater into sensitive environments. UV and ozone units have a compact footprint. If water is turbid (cloudy

³⁰ Zagorodni, A. (2006) *Ion Exchange Materials: Properties and Applications*, Elsevier, Amsterdam.

³¹ Sydney Water (2009) *Water Treatment Options*. Sydney Water. Available at <http://www.sydneywater.com.au/Publications/FactSheets/WaterTreatmentOptions.pdf> Accessed 15 May 2010

³² Zagorodni, A. (2006) *Ion Exchange Materials: Properties and Applications*, Elsevier, Amsterdam.

³³ Sydney Water (2009) *Water Treatment Options*. Sydney Water. Available at <http://www.sydneywater.com.au/Publications/FactSheets/WaterTreatmentOptions.pdf> Accessed 15 May 2010

with suspended solids) or if contact times are too low, disinfection will be less effective. Contaminants such as ammonia can also make chlorine ineffective. Chlorination can result in disinfection by-products. Chlorine is a hazardous product and needs care in handling and storage. Chlorine needs a large tank as it must remain in contact with the effluent for a set time for disinfection to be effective. Ultra-violet and ozone do not provide residual disinfection. Ultra-violet lamps and ozone generators need maintenance to provide consistent performance.

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