University of Southern Queensland

Faculty of Engineering and Surveying

ADVANCED WASTEWATER TREATMENT SYSTEMS

A dissertation submitted by

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towards the degree of

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ABSTRACT

Technical progress in the field of municipal wastewater treatment, which includes removal of eutrophicating pollution loads, has in the past few years significantly improved the process flow of sewage treatment plants.

More attention is now being paid to the high number of disease-causing germs in the sewage treatment plant effluent. Micro and ultra filtration, combined with the activated sludge process, has turned out in recent years to be a suitable method for minimising the effluent load. Tightening discharge standards for sewage treatment effluents can thus be met, without the need for the conventional aeration and secondary clarification tanks or filtration and disinfection plants. Membrane bioreactor technology provides a good alternative to the conventional treatment of municipal wastewater (Huber Technology, 2004).

- Most of the current regulatory requirements will be met by the membrane separation step.
- Membrane bioreactor technology is a space saving technique. Its module-based design allows the capacity to be easily increased when needed.
- Membranes will continue to decrease in price in the coming years.
- With improved effluent quality, re-use of the formerly wasted effluent is possible, which makes it a sustainable technology.
- It combines the biological treatment with a membrane separation step.

Because of this combination it has several advantages over conventional treatment by activated sludge followed by a settling tank.

- The settling tank is unnecessary because of the membrane separation; submerged membrane bioreactors can be up to 5 times smaller than a conventional activated sludge plant.
- Membrane bioreactors can be operated at mixed liquor suspended solids of up to 20,000 mg/L.
- Biomass concentration can be greater than in conventional systems, which reduces reactor volume.
- The membrane can retain soluble material with a high molecular weight, improving its biodegradation in the bioreactor.
- Good effluent quality.
- Good disinfection capability, with significant bacterial and viral reductions achievable using UF and MF membranes.

This paper describes the activated sludge treatment and the membrane bioreactor processes, using Melbourne Water’s Western Treatment plant at Werribee, in Victoria, and CitiWater’s Magnetic Island plant, in Queensland, as examples of the treatment processes.

Sufficient information is given to permit an understanding of the two processes and their relationships. The more recent MBR technology can be seen as an emulation of the natural filtration processes occurring in broad acre treatment, without the large tracts of land area, or the plant and the number of required processes needed for later advancements.

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GLOSSARY OF TERMS

BOD	Biochemical Oxygen Demand.
COD	Chemical Oxygen Demand - the measure of the amount of oxygen required to oxidize organic and oxidizable inorganic compounds in water. The COD test is used to determine the degree of pollution in water.
BOD & COD	Measurements of the strength of the waste.
RBCOD	Readily Biodegradable Chemical Oxygen Demand.
VFA	Volatile Fatty Acid.
SS	Suspended Solids.
VSS	Volatile Suspended Solids.
ASB	Activated Sludge Basin.
MLSS	Mixed Liquor Suspended Solids.
MLVSS	Mixed Liquor Volatile Suspended Solids.
ASP	Activated Sludge Plant.
HRT	Hydraulic Retention Time.
SRT	Solids Retention Time.
DO	Dissolved Oxygen.
DAF	Dissolved Air Flotation.
Aerobic	High in dissolved molecular oxygen.
Anoxic	Low dissolved molecular oxygen but has alternative sources of oxygen available (eg nitrate, sulphate).
Anaerobic	No dissolved molecular oxygen and no other sources of oxygen.
Organic	Pertains to material having its origin in living organisms, which usually have carbon as the predominant component of their chemical structure.

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CHAPTER 1 INTRODUCTION

1.1 Primary, Secondary, and Tertiary Wastewater treatment

Many industrial treatment plants were constructed in the 1970s and 1980s. Discharge criteria required the installation of facilities that performed what is now called primary treatment of wastewater. This involved using screens and sedimentation tanks to remove most of the materials in the wastewater that float or settle.

As subsequent discharge criteria were tightened, secondary treatment became necessary. Secondary treatment is accomplished by bringing together waste, bacteria and oxygen in trickling filters or the activated sludge process. Bacteria are used to consume the organic parts of the wastewater.

Facilities, and their designers are now considering and installing tertiary treatment facilities to comply with the latest regulatory and permit parameters. These advanced treatment processes go beyond conventional secondary treatment and include the removal of recalcitrant organic compounds, as well as excess nutrients such as nitrogen and phosphorus.

1.2 Project Aim

The focus and the emphasis for the project is the membrane bioreactor: -

- The types available.
- Particular design features.
- Operational characteristics and applications.
- Advantages and/or limitations.
- The science and the technology.
- Performance.

The project investigates the characteristics and operational properties of the membrane bioreactor, including: -

- The identification of the stringent processes used to select an MBR plant.
- A discussion of the construction, commissioning and operation of an MBR plant.
- A comparison with the activated sludge system (and possibly other systems) in treating wastewater.

The membrane bioreactor (MBR) installed at Picnic Bay, Magnetic Island, and the treatment plant at Werribee, Melbourne will be used as the primary examples upon which to illustrate the processes of membrane bioreactors and activated sludge treatments in general. Figure 1 below is given as a simple illustration of the processes and their similarities and configurations.

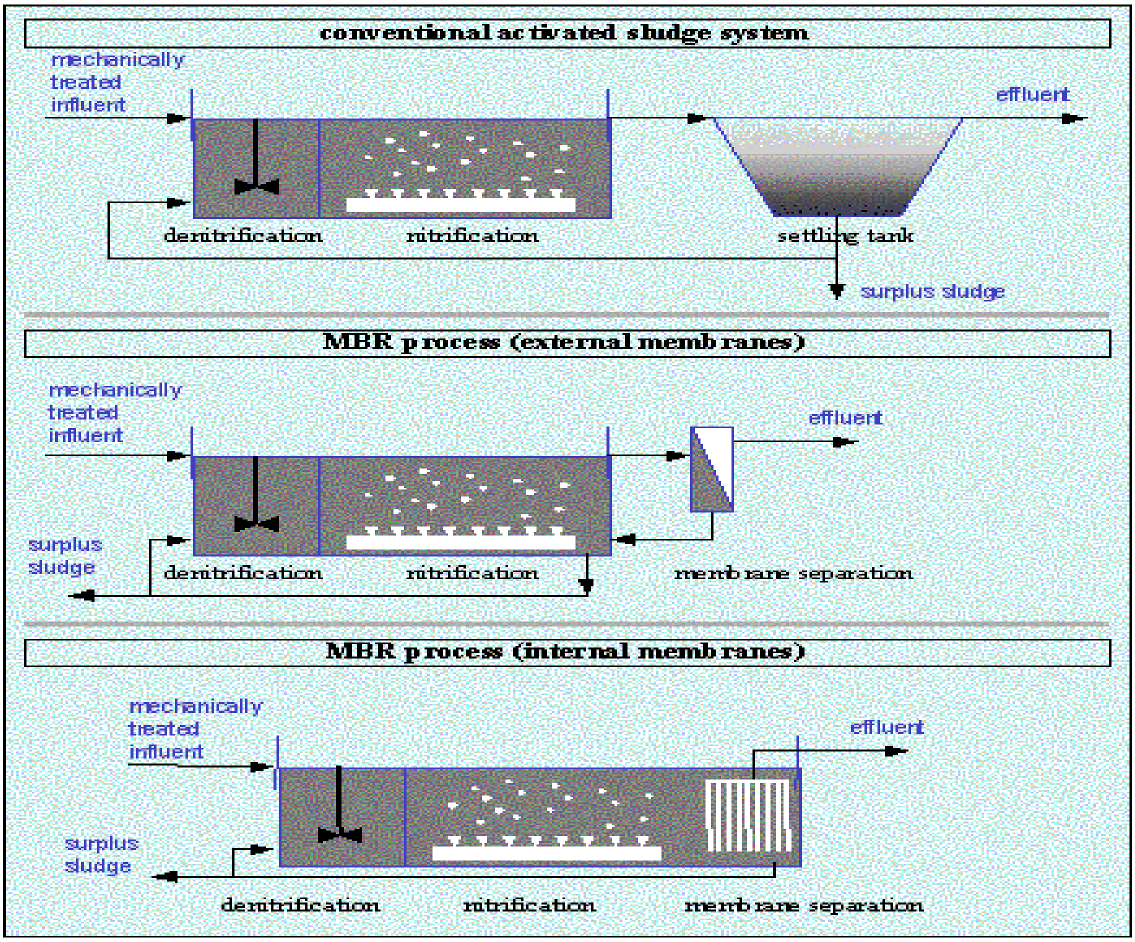

Fig. 1 Activated Sludge and MBR Processes
(Evenblij, 2004)

CHAPTER 2 WERRIBEE SEWAGE TREATMENT FARM

2.1 The Werribee plant

The Werribee plant, with its combination of land treatment and lagoons, was conceived in the 1880s and currently treats about 400 ML per day, 54 % of Melbourne's sewage from 1.6 million people. It is one of the principal land treatment systems in the world (Melbourne Water, 2004c).

Fig. 2 Werribee Sewerage Farm
(Australian Academy of Technological Sciences and Engineering, 1988)

It is one of the largest sewage treatment plants in the world, covering 10,815 hectares - about the size of Phillip Island (Melbourne Water, 2004b).

For comparison the area of the whole of Magnetic Island, Queensland, is 5184 hectares (Magnetic Island Information, 2004).

2.2 Werribee land and grass filtration methods

Three methods of sewage treatment are used at the Western Treatment Plant in Werribee depending on the season and the inflow of sewage.

- Lagoons are for peak daily and wet weather flow all year round.

- Land filtration is used during periods of high evaporation from around October to April. Sewage is applied to the land to grow grass. The disadvantage is that, in the winter, when the land least needs the application of sewage, the volume to be treated is the greatest.

- Grass filtration is used during periods of low evaporation when land filtration is not practical (ie between May and September). Sewage is run over, rather than into the land, and the grass is used to increase the area of exposure to light and air.

Land and grass filtration processes are being phased out. They will be decommissioned by 2005 and replaced by the lagoon treatment systems which have been enhanced with activated sludge technology.

2.3 Werribee lagoon treatment processes

Lagoon treatment operates all year round treating peak daily and wet weather flows. Surface areas reach up to 289 hectares, each containing 10 to 12 ponds.

Sewage travels slowly under gravity through the series of connected ponds, which contain high concentrations of naturally occurring bacteria. The bacteria convert the organic and inorganic nutrients in the sewage into bacteria cells and inorganic products like carbon dioxide, water, ammonia and phosphate. These inorganic products are then consumed by algae.

The initial pond in the major lagoon systems is partly covered to collect gases from the bacterial breakdown of the solids settled from the sewage. These gases contain methane and odorous compounds and are combusted to produce electricity and non-odorous gaseous by-products.

The following is an explanation of the treatment process that takes place in each lagoon:

1. Sewage enters the anaerobic reactor.
2. Bacteria digest the organic material in the sewage, producing methane, carbon dioxide and odorous gases.
3. The gases rise to the top of the lagoon. In some lagoons, these gases such as methane are collected and used as a fuel to generate electricity.
4. Sludge containing heavy metals and some chemicals settle out to the floor of the pond.
5. Sewage moves into the aerobic ponds.
6. Algae grow in the pond, feeding on the nutrients and trace elements in the sewage.
7. Nitrogen is removed by bacteria and algae, which are then eaten by zooplankton.
8. Birds feed on the algae and zooplankton.
9. Effluent flows into Port Phillip Bay after 60 to 80 days of treatment.

The older lagoons require two to three months to treat sewage; the modern lagoons require only one month to treat sewage. The effluent in the final pond can also be recycled for irrigation, including grass, grapevines or orchards.

2.4 Werribee activated sludge plant

As part of the Western Treatment Plant Environment Improvement Project works, an activated sludge plant was commissioned, on 3rd April 2001, in the 5th pond of the 55 East lagoon system and a second plant is presently being constructed in the 25 West lagoon system.

The removal of nitrogen from the sewage is increased in the activated sludge plant by turning it into nitrogen gas. Secondary treated effluent flows into Port Phillip Bay. The Western Treatment Plant inputs about 50 per cent of nitrogen to Port Phillip Bay. The other 50 per cent enters Port Phillip Bay via natural water catchments. Most of the nitrogen in Melbourne's waterways comes from fertilisers.

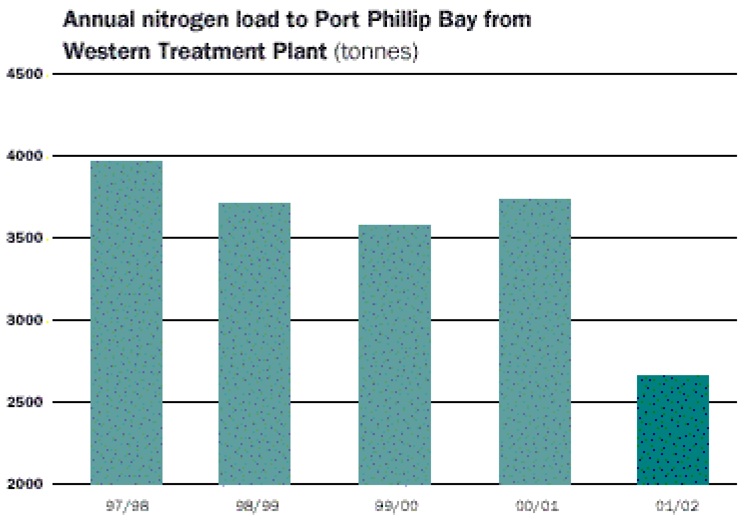

Fig. 3 Annual nitrogen load to Port Phillip Bay
(Melbourne Water, 2004f)

The reduction achieved is attributed to operating the 55 East activated sludge plant, water recycling and a lower annual inflow (Melbourne Water, 2004f).

2.5 Werribee activated sludge plant processes

The 55 East activated sludge plant takes up an area of approximately 200m by 500m with half the area dedicated to the activated sludge basin and the other half comprising clarifiers. Within the sludge basin are four quadrants, two of which are operated to create anoxic conditions and two quadrants, which are operated to create aerobic conditions.

Flow from the last facultative pond enters the first quadrant of the activated sludge plant and is mixed with return activated sludge, which is a large recycle from the fourth quadrant containing nitrates and a high strength chemical oxygen demand feed from the anaerobic reactor. The anoxic condition required for denitrification is created by the presence of nitrates and depletion of oxygen due to the addition of the high strength chemical oxygen substrate. The anoxic conditions provided by the first and second quadrants ensures that the nitrates are sufficiently reduced. Mixing occurs in both anoxic quadrants to ensure sludge stays dispersed through the water for maximum biological activity.

Aeration is provided in the third and fourth quadrants to ensure aerobic conditions conducive for the conversion of ammonia to nitrates. A large recycle flow returns the nitrates to the anoxic zones to be denitrified and so completes the removal of nitrogen nutrients. The level of aeration and mixing provided selects for bacteria that forms a biological floc, which settles rapidly so that bacteria can be separated from the water in the clarification step.

In the clarifiers, the mixed liquor of water and bacterial flocs is separated into a clear overflow stream, which is directed to ponds 5 to 10 for disinfection, and an underflow containing the settled bacterial flocs, which is returned to the activated sludge basin (RAS) to boost the bacterial population (Melbourne Water, 2004g).

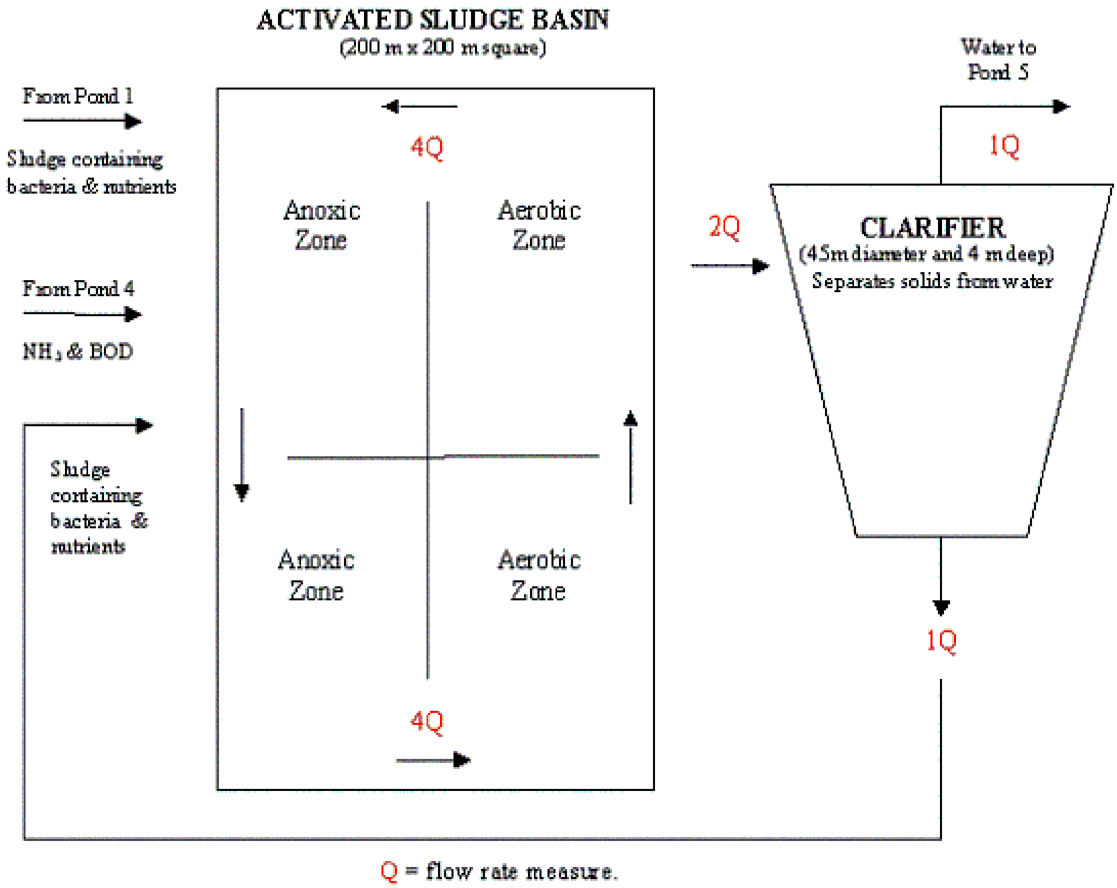

Fig. 4 Activated Sludge Basin
(Melbourne Water, 2004g)

CHAPTER 3 ACTIVATED SLUDGE

3.1 Development

The activated sludge process was developed by accident by two Englishmen, Arden and Lockett. During development Arden and Lockett reported the results of experiments in 1914, and coined the term 'active sludge'. These were all batch units, and the process was not useable until continuous units were developed. The first active sludge plants were both completed in 1917 at Withington, England, and Houston, Texas. The basic premise of the activated sludge process is that all organics can be converted by aerobic biological microorganisms to inorganics, inert organics, CO_2 and H_2O, and more organisms. The influent waters, containing rapidly degradable organics, are brought into contact with a mass of organisms, which use these organisms for food. By separating the organisms from the fluid after this contact, we can let the organisms digest the food for a while and when they get hungry use the organisms over again. This provides a net increase of organisms, some of which are wasted. This then becomes waste-activated sludge.

Cheremisinoff (1994) states that biological treatment is typically applicable to and used in aqueous streams with organic contaminants. Influent waste streams may contain either dissolved or insoluble organics amenable to biodegradation. Biological management of hazardous wastes and wastewaters typically results in: -

- Volume reduction with disposal
- Detoxification

Wastewaters are usually composed of a complex matrix of compounds varying in concentration and toxicity. Contaminants may be degradable, or recalcitrant in varying degrees. Physical-chemical treatments may be required to render the wastewater less inhibitory to microbial treatment and/or ensure removal of non-biodegradable compounds. Engineered systems have been developed for the treatment of contaminated wastewaters and wastes.

3.2 Nitrogen in wastewater

Nitrogen enters the wastewater in urine or from industry (tanneries) and cleaning products (mainly as amines). In waterways nitrogen in wastewater acts as additional nutrient and increases the chance of eutrophication occurring. This can result in an abundance of opportunistic algae, weeds and plants. The increase in total biomass also increases the amount of microorganisms, which are involved in breaking down dead matter. The overall result is a decrease in the amount of dissolved oxygen present in the water due to the decomposition of plants, algae, bacteria and other microorganisms. This therefore has an adverse effect on any other organisms that rely on the dissolved oxygen to survive.

Most of the nitrogen in waterways comes from fertilisers.

High levels of phosphorus cause a similar impact on waterways to nitrogen. Nitrogen is more often the problem in salt waterways whereas phosphorus tends to affect fresh waterways. Phosphorus is found mainly in detergents (Melbourne Water, 2004e).

3.3 Activated sludge chemical and biological processes

The objectives of the activated sludge process are to:

- Carry out the necessary biological treatment of the wastewater.
- Reduce the volume of excess sludge solids, which must be disposed of.
- Remove substances that have a demand for oxygen from the system.
- Provide the reliable and controllable removal of nitrogen through a nitrification/denitrification process.

3.3.1 Removal of Organic Carbon

The types of organic material removed are: -

- Biodegradable (soluble or particulate) - Biodegradable soluble material is used up very quickly in less than 10 minutes. Biodegradable particulate material is dissolved using enzymes and then assimilated.
- Non-biodegradable (soluble and particulate) - Non-biodegradable soluble material passes through the activated sludge plant unaffected. Non-biodegradable particulate is removed in clarification.

Bacteria use the organic material as food for energy and cell synthesis.

3.3.2 Removal of Nitrogen

3.3.2.1 Nitrification in an aerobic environment

- Dissolved ammonia (NH_3) is converted to dissolved nitrite (NO_2) by autotrophic ammonia oxidising bacteria (typically *nitrosomonas nitrosomonas*, *nitrobacter and nitrospira*).
- Dissolved nitrite (NO_2) is converted to dissolved nitrate (NO_3) by autotrophic nitrite oxidizing bacteria (typically *nitrobacter*).

  <u>Aerobic reaction</u>

- Organics + O_2 bacteria new cells + CO_2 + H_2O

3.3.2.3 Denitrification in an anoxic environment

- Dissolved nitrate (NO_3) in the presence of BOD is reduced to nitrogen gas by heterotrophic bacteria (typically *pseudomonas*), which use the nitrate as an alternative oxygen source (Melbourne Water, 2004e).

  <u>Anaerobic reaction</u>

- Organics acid forming bacteria Organic acids + CH_4, H_2S, H_2O, CO_2 or N_2 acid splitting methane forming bacteria CH_4 and CO_2

- Benjes (1980, p.11) states that aerobic biological waste treatment, whether by suspended growth (activated sludge) or attached growth (trickling filters), follows basic concepts. The process converts raw waste organics to bacterial organisms, which are subsequently separated from the liquid stream. This requires a medium for bacterial growth and oxygen for organic conversion to cells.

- In suspended-growth treatment, bacteria are flocculated in a liquid medium and oxygen is supplied to the liquid.
- In attached-growth systems bacteria is grown on a fixed surface and wastewater is passed over that surface.

Oxygen is supplied by the aeration effect of exposing the wastewater to air. The oxygen requirements for each system are similar.

The types of nitrogen are: -

- Proteins and organic compounds containing amino groups (NH_2)
- Oxidised nitrogen - nitrate (NO_3^-), nitrite (NO_2^-)
- Ammonia nitrogen (NH_4^+, NH_3)

1st stage - Ammonification

- Break up proteins and organic compounds to form ammonia
- $N + O_2$ $NH_3 / NH_4^+ + CO_2$
- organic nitrogen + oxygen ammonia + carbon dioxide

2nd - stage - Nitrification (aerobic zone: activated sludge basin)

- Oxidise ammonia to nitrate.
- Bacteria *Nitrosomonas, Nitrobacter and Nitrospira*.
- Affected by sludge age, dissolved O_2, temperature and pH.
- 2 step process:

1. NH_4^+ + 1 ½ O_2 *Nitrosomanas and Nitrospira* NO_2^- + H_2O + $2H^+$

Ammonia + oxygen nitrite + water + hydrogen ions (acid)

2. NO_2^{2-} + ½ O_2 *Nitrosomanas and Nitrospira* NO_3^-

nitrite + oxygen nitrate

This requires 4.57 mg O_2 / mg of N in NH_3 and reduces alkalinity by 7.1 mg $CaCo_3$ / mg of N in NH_3.

3rd stage - Denitrification

- Reduce nitrate to nitrogen gas (mostly in anoxic zone in Activated
- Sludge Basin, but minimal in aerobic zone).
- Organic carbon is necessary for denitrification.
- Reaction occurs faster than nitrification.
- Needs carbon source, nitrates, bacteria & absence of dissolved O_2.
- Equivalent to 2.9 mg O_2 / mg of N in NO_3 denitrified.
- Increases alkalinity by 3.6 mg $CaCO_3$ / mg of N in NO_3

$2NO_3^-$ + $2CH_3OH$ + H_2CO_3 *Pseudomonas bacteria* N_2 + $2CO_2$ + $4H_2O$ + HCO_3^-

nitrate + organics (eg methanol) + bicarbonate nitrogen + carbon dioxide + water + carbonate (Melbourne Water, 2004e).

Table 1 below gives typical results for the processed sewage after treatment by the activated sludge process.

Table 1 Effluent Quality - Lagoon 55 East

(Melbourne Water, 2004e)

Activated Sludge Plant	**Results**
	(mg/L)
Biochemical Oxygen Demand	< = 20
Suspended Solids	< = 30
Ammonia	< = 3
Nitrogen	< = 15
Phosphorus	< = 10
Faecal coliforms	< = 1000/mL

3.4 Recycled water quality

The quality of recycled water produced by this system is currently rated as Class B, as defined by the Guidelines for Reclaimed Water produced by the EPA Victoria. Melbourne Water is currently undergoing a twelve month testing regime in conjunction with EPA Victoria to investigate the steps required to make the recycled water a Class A product. Under this program a number of additional Class A parameters are being monitored weekly - pH, Biological Oxygen Demand, Suspended Solids, Turbidity, Nitrogen, Phosphorous and E coli (Melbourne Water, 2004g). The classes of reclaimed water and the corresponding standards for biological treatment and pathogen reduction are shown below as Table 2. The range of uses for the different classes of reclaimed water is shown in the following Table 3.

Table 2 Classes of reclaimed water and corresponding standards for biological treatment and pathogen reduction

(Melbourne Water, 2004g)

Class	Water quality objectives	Treatment processes
A	< 10 E.coli org/100 mL Turbidity < 2 NTU4 < 10 / 5 mg/L BOD / SS pH 6 - 95 1 mg/L Cl2 residual	Tertiary and pathogen reduction with sufficient log reductions to achieve: < 10 E.coli per 100 mL; < 1 protozoa per 50 litres; & < 1 virus per 50 litres.
B	< 100 E.coli org/100 mL pH 6 - 95 < 20 / 30 mg/L BOD / SSB	Secondary and pathogen reduction (including helminth reduction for cattle grazing)
C	< 1000 E.coli org/100 mL pH 6 - 95 < 20 / 30 mg/L BOD / SSB	Secondary and pathogen reduction (including helminth reduction for cattle grazing)
D	<10000 E.coli org/100 mL pH 6 - 95 < 20 / 30 mg/L BOD / SSB	Secondary

Table 3 Range of uses for classes of reclaimed water

(EPA Victoria, June 2003)

Class	Range of uses (includes all lower class uses)
A	Urban (non- potable): with uncontrolled public access Agricultural: e.g. human food crops consumed raw Industrial: open systems with worker exposure potential
B	Agricultural: e.g. dairy cattle grazing Industrial: e.g. wash down water Urban (non-potable) with controlled public access
C	Agricultural: e.g. human food crops cooked/processed, grazing/fodder for livestock Industrial: systems with no potential worker exposure
D	Agricultural: non-food crops including instant turf, woodlots, flowers

Where Class C or D is via treatment lagoons, although design limits of 20 milligrams per litre BOD and 30 milligrams per litre SS apply, only BOD is used for ongoing confirmation of plant performance. A correlation between process performance and BOD / filtered BOD should be established and in the event of an algal bloom, the filtered BOD should be less than 20 milligrams per litre (Melbourne Water, 2004g).

3.5 Chemicals and Drinking Water

Water of a high quality is a critical factor for human activity. The standards for drinking water are based upon the necessity to avoid any health hazard. However, it is impossible to eliminate some classes of environmental contaminants, such as metals completely by conventional water purification methods. Economical growth calls for more process water, some of which is just used to dilute wastewater down to the legal limits required for release into the next watercourse and into the freshwater reservoirs. Caetano et al (1995) state that 95 % of global freshwater reserves consist of groundwater. Diminishing freshwater reserves coupled with rising quantities of chemicals present two environmental problems.

Caetano et al (1995) consider that the dispersion of environmental chemicals from industrial wastewaters must be limited; the volumes of waste materials drastically reduced; and that industrial process water must be recovered for re-use. Many chemical contaminants are found in the sewage sludge derived from wastewater (and the figures from several countries are given in Table 4 below.

Table 4 Metal content in sewage sludges
(Caetano et al, 1995)

	Sweden		England and Wales		Michigan	
Element	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**
Zinc	705-14,700	1,567	1700 - 49,000	3,000	72 - 16,400	2,200
Copper	52 - 3,300	560	200 -8,000	800	84 - 10,400	700
Lead	52 - 2,917	180	120 -3,000	700	80 - 2,600	480
Chromium	20 - 40,615	86	40 - 8,800	250	22 - 300,000	380
Nickel	16 - 2,120	51	20 - 5,300	80	52 - 2,977	52
Cadmium	2.3 - 172	6.7	60 - 1,500	-	-	112
Manganese	73 - 3,861	384	150 -2,500	400	-	-

A number of specific sources have been identified. The cadmium concentrations found in the wastewater derived environmental contaminants are extremely high.

Zinc ores contain between 0.1 % and 1 % of cadmium; as a consequence, freshly mined cadmium in the order of 13.5 tonnes to 135 tonnes are added to the global cadmium cycle every year. The cadmium element shows no valency changes, nor a marked tendency to form hydrophobic organic compounds, and therefore follows quite predictable routes. Other elements while changing valency and/or forming metal-organic compounds may follow routes which are divergent from the original ones. One example is mercury.

Inorganic mercury species, such as Hg_2^+, Hg^+ and HgO are transported into the hydrosphere, and associate strongly with organic matter, amorphous iron phases and clay minerals. Only 1 % of the total mercury content in sediments is found in the interstitial water and is available for transport and take-up. The organic species CH_3Hg^+ and CH_3hHg formed in situ by bacterial activities are highly lipid-soluble and quickly introduced into the food chain where they are transported to higher trophic levels. They are also directly released into the atmosphere along with gases, such as CH_4, where the mercury may conclude its cycle by demethylation and formation of HgO, ready for further dispersion.

Another case is the arsenic cycle. Arsenates have been introduced into the environment as pesticides, wood protectives and colour pigments. Once deposited either in the hydrosphere, or the pedosphere, the relatively non toxic As_2^+ compounds are transformed into highly toxic As_3^+ compounds and finally into volatile methylarsines, which may reach the atmosphere and spread out further.

It is therefore important that these chemicals are removed and contained before they can disperse. In fact Culp (1978) cites an article from the August 1971 *Journal of the Water Pollution Control Federation*, which presents detailed information on the Denver water supply concerning the differences in the city water supply and the wastewater effluent. Culp asserts from this article that studies made at a number of places indicate that two parts of makeup water must be added to one part of recycled reclaimed water in order to prevent the development of excessive concentrations of certain chemical constituents, which are not completely removed in treatment.

Caetano et al (1995) conclude that the potential of cross flow membrane techniques as tools in safeguarding and protecting the aquatic environment as a whole, and the drinking water resources in particular, should be systematically explored. The varying quality criteria for the control of trace metals in water are given below in Table 5.

Table 5 Drinking water quality criteria for trace metals which might affect public health. (Caetano et al, 1995)

	Japan	**USSR**	**WHO**	**NAS**	**Australia**	**US**	**FRG**
Element	**1968**	**1970**	**1971**	**1972**	**1973**	**1975**	**1975**
Arsenic	50	50	50	100	50	50	40
Barium		4,000	1,000	1,000	1,000	1,000	
Cadmium		10	10	10	10	10	6
Chromium	50	100	50	50	50	50	50
Copper	10,000	100	50	1,000	10,000		
Lead	100	100	100	50	50	50	40
Mercury	1	5		2		2	4
Selenium		1	10	10	10	10	8
Silver					50	50	
Zinc	100	1,000	5,000	5,000	5,000		2,000

CHAPTER 4 WASTEWATER TREATMENT PROCESSES AND EQUIPMENT

4.1 Treatment Processes

Waste treatment aims at the removal of unwanted components in wastewaters in order to provide safe discharge into the environment. This can be achieved by using physical, chemical and biological means, either alone or in combination. A treatment plant is like an assembly in a factory where the various steps in purification are arranged in such a sequence that the quality of the output of one step is acceptable in the next step.

Physical treatment methods such as screening, sedimentation, and skimming remove floating objects, grit, oil and grease.

Chemical treatment methods such as precipitation, pH adjustment, coagulation, oxidation, and reduction, remove toxic materials and colloidal impurities.

Finally, dissolved organics are removed by biological treatment methods.

Tertiary treatment methods are used for further purification and for reuse of treated wastewater for various purposes.

The treatment units used require proper design, construction, commissioning, operation and maintenance to meet the discharge standards required by regulatory authorities (Sastry et al., 1995).

Aquatec-Maxcon is Australia's leading provider of water and wastewater technology and equipment.
Installations include 89 x 30 kW floating aerators for Werribee stratified lagoons.
Their alternative process configurations have been tabulated below in Table 6.

Table 6 Wastewater Treatment Processes

(Aquatec-Maxcon, 2004a)

Alternative treatment processes				
	1	**2**	**3**	**4**
	Grit removal	Grit removal	Grit removal	Grit removal
Primary Anoxic	Clarification	Clarification	Clarification	Clarification
Aerobic		Aeration	Aeration	Aeration
Secondary Anoxic		Secondary clarifier	Secondary clarifier	Secondary clarifier
Membrane Basin	Sludge thickening	Sludge thickening	Filtration	MBR
	Digestion	Digestion	UV disinfection	
	Dewatering	Dewatering		
	Drying	Drying		

4.2 Screening Removal System

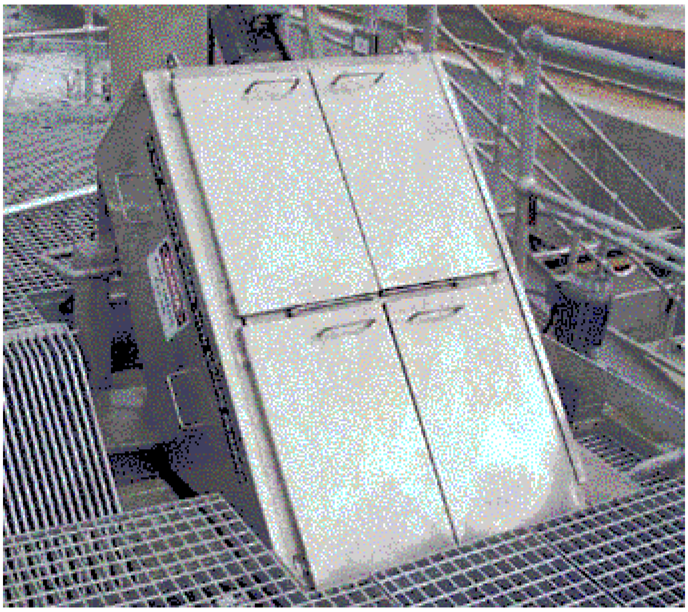

Fig. 5 Screening Removal System
(Aquatec-Maxcon, 2004a)

The wastewater, or raw water from rivers or seawater inlets, contains large floating objects, fibrous material or other foreign objects, which will cause problems for downstream treatment and pumping equipment. These non-degradable objects have to be removed or they may lead to blockages, these objects are called screenings. Manual bar screens may be adequate for smaller plants, however, mechanical screens are normally used to remove the screenings from the water.

Mechanical screens come with different apertures and types. Generally, all screens with an aperture less than 10 mm diameter or gap for slot opening are called fine screens. The choice of aperture will affect the quantity and quality of the screening captured. If using fine screening in conjunction with a gravity flow system, faecal matter will be captured together with screenings. This has to be borne in mind when designing the screening handling system. Various types of screening equipment are used to suit different applications.

4.2.1 Fine Screens

- Travelling belt type fine screen for water intake
- Above channel rotating drum ccreen
- In channel trommel screen
- Walking step type fine screen
- Sieve bend static screen

4.2.2 Coarse Screen (Bar Screen)

- Inclined type
- Multiple raked
- Cable driven
- Climber type
- Back rake chain and sprocket type

4.2.3 Rotary Type

- Fully rotary
- Semi-rotary

The choice of type of bar screen depends on the channel depth and width, preference for above water moving parts, and headroom requirements.

4.3 Grit Removal System

Fig. 6 Grit Removal
(Aquatec-Maxcon, 2004a)

Grit particles, which are smaller than the aperture of the screen, will pass through and cause abrasive problems on pipes and pumps and sludge handling equipment. Also, the grit particles can settle in channels, aeration tanks floor and sludge digesters, which can create maintenance problems. Therefore, a grit removal system is required for most sewage treatment plants.

Removal of grit is achieved by differential sedimentation, in which the flow velocity is so controlled that grit may settle, but most of the organics are retained in suspension. Velocity control may be achieved hydraulically, as in constant velocity chambers, by air-induced helical rolling motion, as in aerated chambers, or by mechanically induced vortex chamber.

The grit collected will be transferred by recess impeller grit pump or air lift pump to dewatering devices to reduce the water content. Screw type grit classifier or sieve bend are used for dewatering. Excess water will return back to the inlet channel.

4.4 Clarification

Fig. 7 Clarification
(Aquatec-Maxcon, 2004a)

Gravity sedimentation is one of the most frequently used processes in wastewater treatment. Many wastewaters contain settleable suspended solids that can be removed under quiescent conditions. Particles, solid, liquid, or gaseous that have a different density from that of the suspension medium (water), will settle downward because of gravity or rise to the top because of buoyancy. In other cases where suspended materials do not settle readily, upstream unit processes are used to convert colloidal (non-settleable suspended solids) and soluble pollutants into settleable suspended solids for gravity sedimentation removal. Suspended solids removal is important because of the pollutants associated with the removed solids, such as organics, nutrients (nitrogen, phosphorus), and heavy metals.

Gravity sedimentation occurs in basins frequently called clarifiers.

4.5 Secondary Clarification

Secondary clarifiers are used to remove the settleable suspended solids created in biological treatment processes such as the activated sludge and trickling filter process.

There are various types of Primary and Secondary clarifiers.

4.5.1 Circular

- Peripheral drive
- Centre drive

4.5.2 Rectangular

- Travelling bridge
- Chain and flight
- Wire rope and flight

4.6 Activated Sludge Aeration

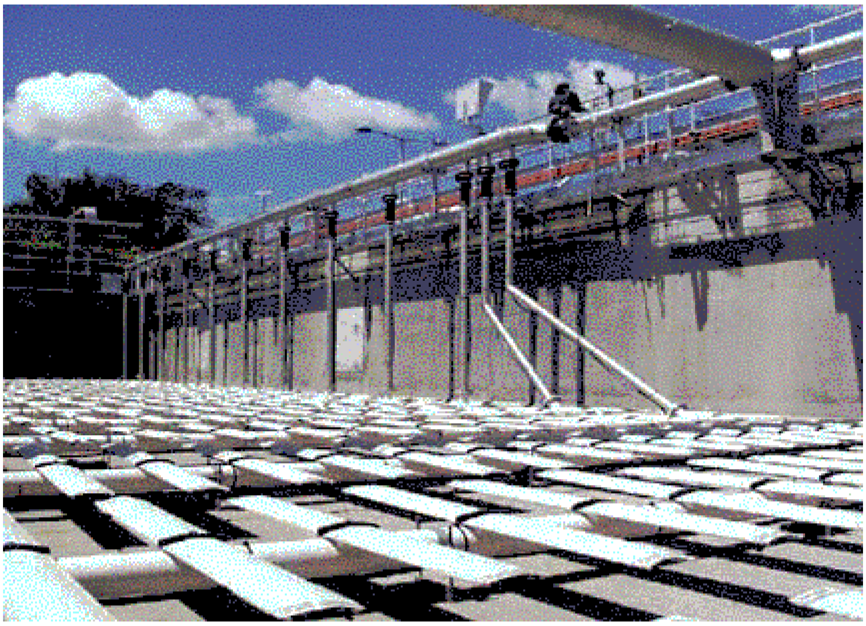

Fig. 8 Diffused Air Aeration
(Aquatec-Maxcon, 2004a)

Diffused Air Aeration systems are available for continuous or intermittent systems in conventional basins, lagoons and racetrack or circular oxidation ditch configurations. Examples include:

- 75,000 EP racetrack continuous aeration oxidation ditches with ceramic diffusers at Gibson Island, Brisbane and Porirua, New Zealand.
- 100,000 EP intermittent cycle extended aeration plant with membrane diffusers at Quaker's Hill, Sydney.
- Australia's largest ever aeration project for a 210 ML per day peak flow intermittent cycle plant at Black Rock Geelong. This equipment transfers 3,600 kg O_2 per hour.

Aquatec-Maxcon has developed the first entirely Australian designed and manufactured membrane diffuser the Aquablade. This revolutionary patented technology offers material capital and operating savings through improved transfer efficiency and reduced fouling potential. Advantages include:

- Reduced consumption of potable water and chemicals.
- Reduced contract delivery period.
- Better controlled, more accurate testing.
- Surface Aeration.

The surface aerator is available in fixed and floating configurations, which offer the highest available guaranteed oxygen transfer efficiencies demonstrated by infield testing. Installations include: -

- 89 x 30 kW floating aerators for Werribee stratified lagoons near Melbourne.
- 24 x 37 kW / 18kW fixed mount units for Bendigo biological nutrient removal plant.

4.7 Filtration

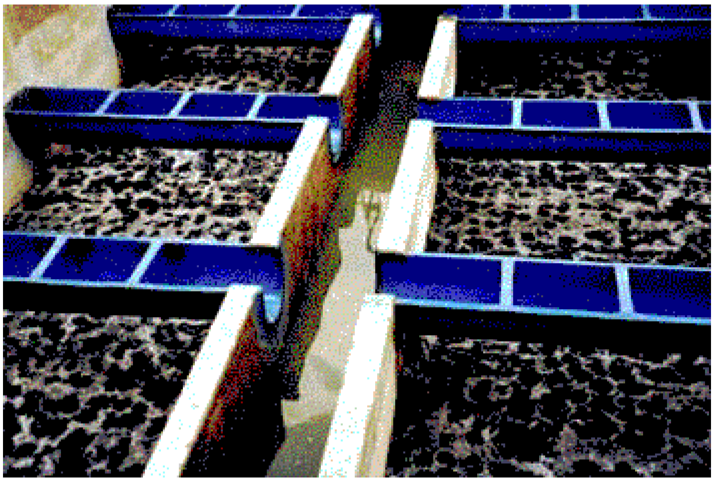

Fig. 9 Filtration
(Aquatec-Maxcon, 2004a)

Granular media filtration systems remove fine non-settleable material. Media systems include silica sand, anthracite, gravel, garnet, manganese greensand and birm - all available in mono, dual, and multimedia form.
Underdrain systems are manufactured in plenum and lateral styles, incorporating slotted dome strainer nozzles.

Backwash systems are available as manual and automatic control and comprise air scour, combined air scour/low rate backwash, low rate backwash and high rate backwash phases as appropriate.

Filter designs available include:

- Conventional open gravity cell.
- Pressure filters.
- Automatic self backwashing filters.
- Filter rate control methods include level controlled, rising level and declining rate.

Filter media systems are designed to suit the specific application and include:

- Mono sand media.
- Coarse deep bed media.
- Dual media (coal/sand).
- Multimedia (coal/sand/garnet).

4.8 Sludge Thickening and Digestion

Fig. 10 Sludge Thickening
(Aquatec-Maxcon, 2004a)

Fig.11 Sludge Digestion
(Aquatec-Maxcon, 2004a)

4.8.1 Aerobic digestion equipment

- Multiport gas mixing valve - a single multi-port valve, which simplifies the mixing valve arrangement.
- Gas lance - guide tube in stainless steel or galvanised mild steel.
- Draft tube - mixing system using gas lift system.

4.8.2 Anaerobic digestion equipment

- Steel digester cover (floating and fixed)

  a) Floating steel digester cover complete with roller guides and water seal.

  b) Fixed digester cover for primary.
- Sludge heat exchanger/heater

  a) Innovative combined boiler/heat exchanger sludge heater. No separated boiler.

  b) Non-clogged tube-in-tube sludge heater.

4.9 Sludge Dewatering

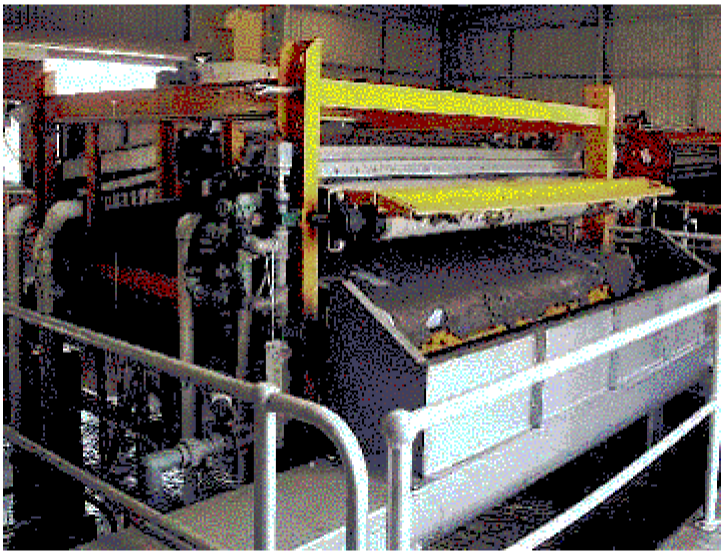

Fig. 12 Sludge Dewatering

(Aquatec-Maxcon, 2004a)

The solids generated by the sewage treatment process need to be dewatered in order to reduce the volume and save on disposal costs.

Different dewatering methods include belt press, centrifuges, screw press. Centrifuges currently achieve 25 to 30 % dry weight for normal sludge de-watering. The system will consist of a sludge conditioning system, dewatering equipment, sludge conveyor and storage silo (Aquatec-Maxcon, 2004a).

4.10 Solar drying of sewage sludge

The end product of all types of sewage works is the cleared water and a more or less liquid mass: the sewage sludge. The volume of the untreated sludge is enormous, as it still contains over 95 % of water. Using different mechanical methods this volume can be reduced significantly, but the water content can only be reduced - depending on the system and investment - to a maximum of generally not less than 65 to 75 %. This means that the remaining mass, which needs to be transported and disposed of, is still high and any type of interim storage is difficult. Moreover, every kilogram of water remaining in the sludge restricts its use and its disposal involves high costs.

Unlike mechanically dehydrated sewage sludge, dried sludge is biologically
stable. The remaining water content is minimal, it does not smell and the product is suited for several means of disposal, such as combustion, land-filling, agriculture. Conventional drying methods, however, require enormous investments and the energy consumption is high. Drying has been considered to be a suitable solution only for big stations.

Fig. 13 Solar drying technology
(Thermo-System Industries, 2004)

In contrast to this, refined solar drying technology requires much lower investments. Fully mechanized, microprocessor-controlled systems have proved to be suitable for small and middle sized plants. The dryers work with or without mechanically dehydrating the sludge before drying. The weight of the dry end product can be less than 10 % of the original - and, in most cases, the odour is comparable to that of soil (Thermo-System Industries, 2004).

CHAPTER 5 MEMBRANE BIOREACTORS

5.1 Membrane bioreactor technology

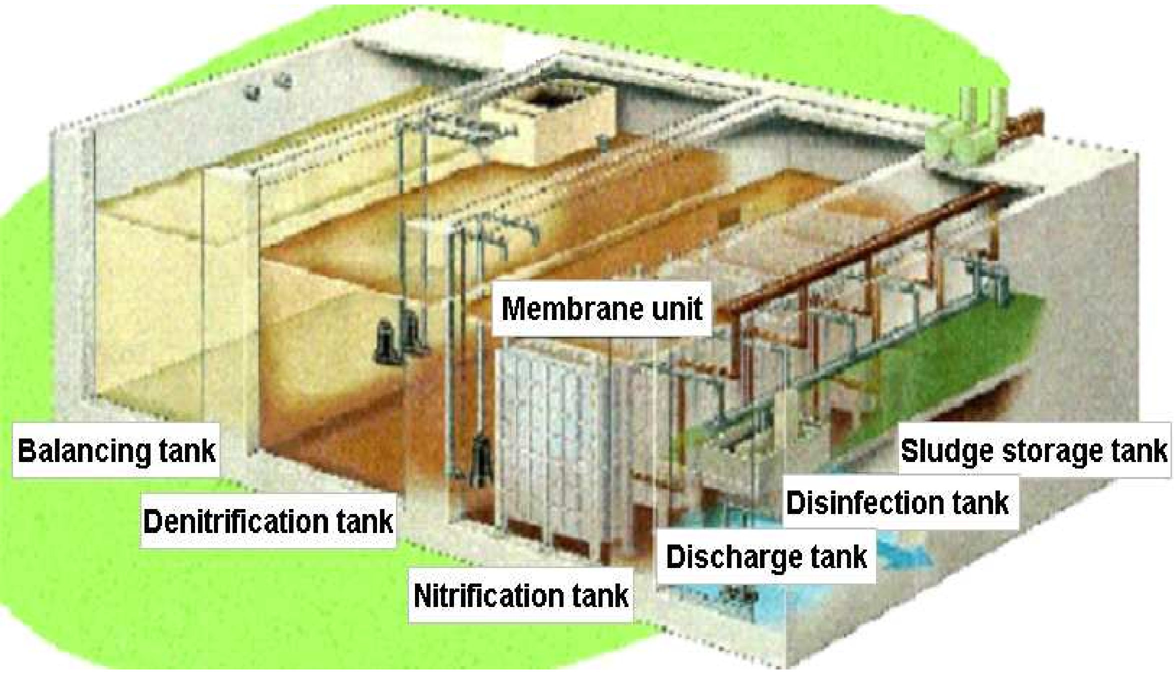

Fig. 14 Membrane bioreactor technology
(Enviroquip, 2004)

Membrane bioreactor technology combines the use of biological processes and membrane technology to treat wastewater and provide organic and suspended solids removal. A high standard of wastewater treatment can be achieved, without the conventional arrangement of aeration tank, settling tank and filtration to produce a tertiary standard effluent of 5: 5: 5 BOD: Suspended Solids: Ammonia. Flow passes through the membranes, while solids remain in the biological treatment system. The membrane bioreactor system combines the benefits of a suspended growth reactor with the solids separation capability of an ultrafilter or microfilter membrane unit. The membrane provides a long solids retention time, usually 30 - 60 days, which can greatly enhance the biological degradation of influent organics.

A membrane bioreactor system can be operated in either an aerobic or anaerobic mode, increasing the spectrum of chemicals suitable for biological treatment. MBR applications have included batch chemical plant effluents, groundwater filtration, landfill leachate, chlorinated solvents in manufacturing plant wastewaters, oily wastes, phosphorous control, and pharmaceutical intermediates.

Membrane bioreactors offer an excellent solution for in-process, at-source treatment applications, and full-scale suspended growth membrane bioreactors have been operating in wastewater treatment systems for more than 20 years (USFilter, 2002).

5.2 Membrane Technology Development

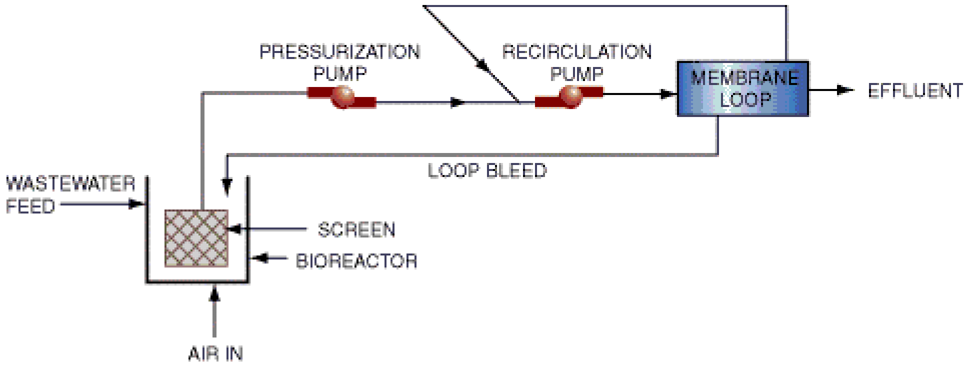

Fig. 15 Simplified process schematic of the Dorr-Oliver MST system - adapted from Bemberis, Hubbard & Leonard, 1971

(Enegess, D. et al., undated)

A process referred to as the Membrane Sewage Treatment (MST) system was developed in the 1960s, in which raw wastewater entered an aerated, suspended growth reactor (see figure above). The reactor contents were continuously withdrawn through a rotating, self-cleaning, drum screen to the membrane step. In the crossflow membrane loop, the reactor contents were recirculated at a rate necessary to ensure maintenance of a high membrane surface velocity in order to minimize the rate of membrane fouling. The membrane component consisted of flat polymeric membrane plates, with a pore size in the range of 0.003 to 0.010 microns.

A large-scale MST system pilot study completed by Dorr-Oliver, USA, involved operation of a 2.27 m^3 per day pilot plant for municipal wastewater treatment, over a period of approximately one year. Treatment performance was said to be excellent but a rapid deterioration in the membrane flux was observed. Powdered activated carbon was added to the bioreactor in an attempt to improve the flux characteristics of the membrane component. The approaches taken to resolve the membrane efficiency issue proved uneconomical when the system was proposed for the treatment of larger wastewater flows of 76 m^3 per day. This development work resulted in a licensing agreement with Sanki Engineering of Tokyo (Stephenson et al, 2000), who installed approximately 20 membrane bioreactor processes between 1974 and 1987. The membrane biomass effluent separation component was also located externally to the bioreactor (see figure below) and relied on a high liquid crossflow velocity of 2 to 5 metres per second, and a high membrane pressure differential of 280 to 400 kPa to achieve filtration.

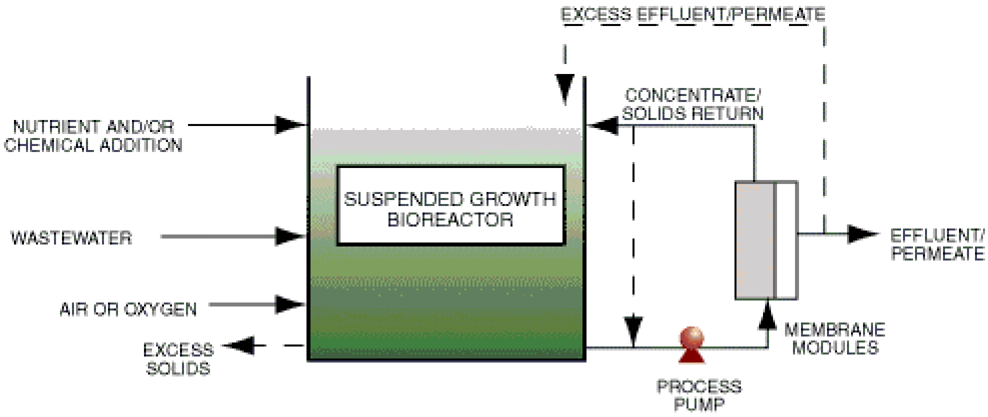

Fig. 16 Simplified schematic of the external membrane MBR configuration (Till, 2001)

The power costs associated with the operation of the external membrane MBR system limited its application to smaller wastewater flows. In the late 1980s, Japanese researchers began to explore application of the MBR technology in which the membranes were mounted directly in the biological reactor (see figure below) and the membrane permeate or biosystem effluent was withdrawn through the membranes by the use of a suction pump.

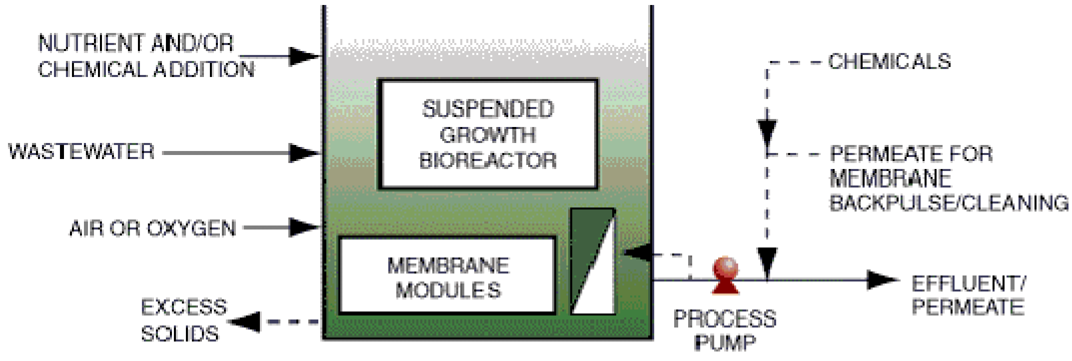

Fig. 17 Simplified schematic of the internal membrane MBR configuration (Till, 2001)

This development ultimately led to the introduction of various commercial, internal membrane MBR systems such as Zenon Environmental's ZeeWeed ® ZenoGem ® system and the Kubota Submerged Membrane Unit (refer to Appendices D & E).

The membrane component of the internal MBR configuration typically involves substantially more membrane area per unit volume of process fluid, relative to the membrane component of the external MBR configuration. The internal MBR operates at a much lower trans membrane pressure of 28 kPa to 56 kPa and effectively operates at a lower liquid crossflow velocity. This meant lower power costs for the operation of the membrane component. Reduced power costs combined with improvements in the efficiency and performance of cross flow membranes have made MBRs a cost effective wastewater treatment solution (Aquatec-Maxcon, 2004a).

However, the large membrane surface area in a high-suspended solids environment makes fluid transfer around the membranes extremely critical. Positive and uniform fluid transfer across all membrane surfaces is necessary in order to prevent an unstable operating environment for the membranes occurring, which could result in increased maintenance and the potential for the solids to pack around the membranes (Till, 2001).

In the US, the first large-scale external membrane MBR system for treatment of industrial wastewater was constructed in 1991. The first large-scale internal membrane MBR system for treatment of industrial wastewater was installed in 1998 (Enegess, D. et al., undated).

5.3 Configuration of Submerged and Sidestream MBR systems

Membrane filtration occurs either within the bioreactor, or externally through recirculation, subject to a pressure drop across the membrane driven by either the hydraulic head or a pump. Aeration within the bioreactor provides the required oxygen transfer for growth of the biomass and mixing of the reactor.

In the submerged (or internal) configuration a coarse bubble diffuser is generally used. This system does not offer very efficient oxygen transfer but the rising bubbles provide a turbulent crossflow velocity (approximately 1 m / s) over the surface of the membrane. This helps to reduce the build up of material at the membrane surface and maintain the flux through the membrane, increasing the operational life cycle of the system. Less frequent and less rigorous cleaning of the membrane is required to restore operational flux compared to the side stream system.

In the side stream (external) configuration the aeration is usually through a fine bubble diffuser, which offers much more efficient oxygen transfer. The crossflow velocity utilized in these systems is usually higher (2 - 4 m / s). As the system is driven by a differential head, the operational flux of the system is higher. The disadvantage of this is that fouling of the membrane is more pronounced and rigorous cleaning regimes are required to restore the operational flux, reducing the useful life of the membrane.

The choice between operating options is dependent upon the application, as both systems have advantages and disadvantages.

5.3.1 Submerged and Sidestream MBR configurations comparison

Submerged MBR: -

- Aeration costs high (~ 90 %).
- Very low liquid pumping costs (higher if suction pump used ~ 28 %).
- Lower flux (higher footprint).
- Less frequent cleaning required.
- Lower operating costs.
- Higher capital costs.

Side stream MBR: -

- Aeration costs low (~ 20 %).
- High pumping costs (60 - 80 %).
- Higher flux (smaller footprint).
- More frequent cleaning required.
- Higher operating costs.
- Lower capital costs.

5.4 Membrane uses

Membranes and membrane separation techniques have grown from a simple laboratory tool to an industrial process with considerable technical and commercial impact. Membranes are used on a large scale to: -

- Produce potable water from the sea by reverse osmosis.
- Clean industrial effluents.
- Recover valuable constituents by electro dialysis.
- Fractionate macromolecular solutions in the food and drug industries by ultra filtration.
- Remove urea and other toxins from the bloodstream by dialysis in an artificial kidney.
- Release drugs such as scopolamine and nitroglycerin, at a predetermined rate in medical treatment.

Although membrane processes may be very different in their mode of operation, in the structures used as separating barriers, and in the driving forces used for the transport of the different chemical components, they have several features in common, which make them attractive as a separation tool. In many cases membrane processes are faster, more efficient, and more economical than conventional separation techniques.

With membranes, the separation is usually performed at ambient temperatures, thus allowing temperature sensitive solvents to be treated without the constituents being damaged or chemically altered. Membranes can also be tailor made so that their properties can be adjusted to a specific separation task (Porter, 1990).

5.5 Membrane Technologies

These processes differ depending on the type of substance to be removed; there is still plenty of scope for technological improvement, and increasing the field of application. The membrane processes, which Caetano (1995) cites as being of practical interest for water purification, are micro filtering, ultra filtering, reverse osmosis and electro dialysis. Membrane types can be broadly placed into four categories, with classification being dependent on the pore size of the membrane. These categories, from largest to smallest pore size, are listed below. Nanofiltration has been included to demonstrate the relativity of the categories.

5.5.1 Micro filtration

- Filtration by particle size.
- Removes e.g. colloidal silica, oil emulsion, collidocillus staphylococcus.
- Used for wastewater treament.
- Membrane size 0.1 μm - 10 μm.

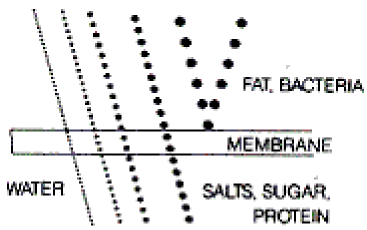

Fig. 18 Microfiltration
(Till, 2001)

This is a dynamic mechanical filtering process performed by means of membranes, which allow selective separation, purification and concentration of organic substances of high molecular weight. Small particles (of the order of a micron), such as those produced by metal surface working, can therefore be separated. The advantages are the low pressures required to obtain the selective separation (0.2 - 0.5 bar) and therefore the low quantities of energy needed for the process. Some of the fields of application of micro filtering in the purification of industrial outflows are:

- Oily emulsions.
- Outflow water from metal finishing treatments.
- Outflow water containing high concentrations of tensioactives.
- Outflow water from painting plants.

5.5.2 Ultra filtration

- Selectively filters only molecules of a specified size and weight.
- Removes e.g. various viruses.
- Used for sterilization, clarification, wastewater treatment.
- Membrane size 1 λ - 0.01 μm.

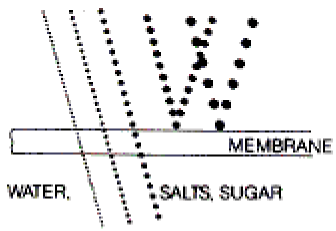

Fig. 19 Ultrafiltration
(Till, 2001)

This is a dynamic filtering process with a predominance of physical (mechanical) phenomena in which chemical phenomena are also involved. The membranes used, polymeric or mineral, allow dissolved salts to pass while they reject high molecular weights selectively. The selectivity depends on the membrane structure and is defined as the cut-off of molecular weight, which the membrane can separate with an efficiency of 90 % (although this definition may not be rigorous depending on the molecular shape).

Commercial membranes applied in ultra filtering can separate substances with a molecular weight between 1.000 and 10.000. Ultra filtering systems generally work in a pressure range between 1.5 and 7 bar.
With industrial discharge waters the fluxes of permeate generally fluctuate between 0.5 and 1 - 5 m^3 / h / m^2 surface, depending on the concentration of the substances to be separated, with energy consumptions varying between 2 and 20 KWh per m^3 of permeate.

The single pass ultra filtering process is the simplest and most commonly used process for water treatment because it allows the recovery of high percentages of permeate (approximately 90 - 95 %).

There has been a relatively recent application of this technique in the metal-finishing sector for the recovery of degreasing baths (the first cleaning bath in metal-finishing processes, for pieces which are still dirty with lubricating substances). The solution to be treated is passed through the membrane at a certain speed and under hydrostatic pressure, obtaining a concentrated fraction of oils and grease for disposal, while the filtrate is recovered and reused to prepare new baths.

5.5.3 Nanofiltration

- Used for partial desalination.
- Removes e.g. sucrose, egg albumin.
- Used for blood osmosis, blood fitration, water purification.
- Membrane size 10 λ - 0.001 µm.

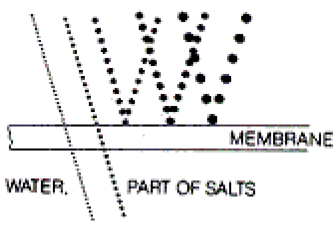

Fig. 20 Nanofiltration
(Till, 2001)

5.5.4 Reverse osmosis

- A filtration process used for complete desalination.
- Used for blood osmosis, blood filtration, water purification.
- Membrane size 10 λ - 0.001 μm

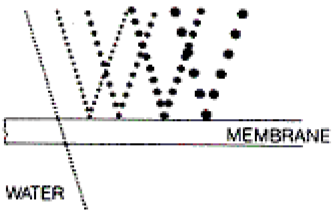

Fig. 21 Reverse osmosis
(Till, 2001)

Industrial effluent treatment, using reverse osmosis, can be applied in the following main sectors: -

- Treatment of outflows containing colourings with their possible recovery.
- Treatment of outflows containing oily emulsions, latex and electrophoretic paints.
- Treatment of outflows from the metal-finishing industry with recovery of concentrated solutions of metal salts and reuse of the water in cleaning.

In addition some industrial sectors, such as precision microelectronics, use the reverse osmosis process together with treatment using resin exchangers to obtain very pure water.

5.5.5 Electro dialysis

This is a process in which electrically charged membranes are used to separate ions from water solutions by the effect of a difference of electric potential.
The electro dialysis group may contain, depending on the type of application, up to 400 cationic and anionic membranes, which visually are very similar to a filter press.

This process may be convenient for very high concentrations (between 0.5 and 1 gram per litre). In the treatment of industrial outflows it is still a little developed technology: its first applications are in fact in metal finishing for the recovery of metals (Caetano et al., 1995).

Increasing the pore size of the membrane has a marked effect on the performance of the membrane and the quality of the filtered effluent, or permeate. Microfiltration membranes will essentially reject particulate matter, whilst reverse osmosis membranes are capable of rejecting macromolecular fractions, such as dissolved salts. The ultrafiltration or microfiltration membranes have pore sizes such that allow water and most solute species to pass through the membrane whilst other larger species, such as solids and microorganisms, are retained.

One of the main features of MBR technology is the ability of the membrane to remove pathogenic organisms, providing disinfection of the effluent. This is particularly important when considering reuse options. The membrane offers a physical barrier to the organisms that is unaffected by the influent quality. Reductions in bacteria and viruses of 4 - 8 log have been reported (Till, 2001).

Table 7 Reduction in microorganisms using different membrane systems (Till, 2001)

Membrane	**Pore Size(mm)**	**Average Log Reduction**	**Bacterial Virus**	**Reference**
MBRs:				
PE (1)	0.1	4.6	Coliphage QB	Chiemchaisri (1992)
PS (1)	0.5	5	TC	Gander (in press)
PS (1)	0.3	ND	TC	Jefferson (1998)
Memtec (2)	0.2	ND	TC	Kolega (1991)
Memcor (2)	0.2	3.8	FC	Till (1998)
Renovexx (2)	0.5-1.5	3.3	FC	Till (1998)
Stork (3)	0.05-0.2	2.5	FC	Tin (1998)
Starcosa (3)	0.2	ND	TC	Till (1998)
DOW (3)	0.2	<7	TC	Till (1998)

(1) Activated sludge within MBR;
(2) Primary sewage effluent;
(3) secondary sewage effluent.
ND - None Detected; TC - Total Coliforms; FC - Faecal Coliforms

5.6 Separation principles

The basic principle of any separation process is that the minimum amount of energy is required to accomplish the separation. Two substances will mix spontaneously when the free enthalpy of the mixture is smaller than the sum of the free enthalpies of the individual substances. The minimum amount of energy necessary to complete separation is at least equal to or larger than the free enthalpy of mixing. In practice the energy requirement for separation will be many times greater than the minimum value. Many different types of separation processes exist and each requires a different amount of energy.

5.7 Membrane materials and properties

Membranes can be made from a large number of different materials. A first classification can be made into two groups, biological and synthetic membranes. Synthetic membranes can be divided into organic and inorganic membranes. The organic membrane materials (polymers or macromolecules) are the most important. The choice of a given polymer as a membrane material is based on very specific properties, originating from structural factors. Basically all polymers can be used as a barrier or membrane material but the chemical and physical properties differ so much that only a limited number are used in practice.

A further classification can be made between the open, porous membranes, which are used in microfiltration and ultrafiltration, and the dense nonporous membranes, used in gas separation and pervaporation. For porous membranes, it is not the choice of material that determines the separation characteristics, but the pore size and the pore size distribution relative to particle or molecular size. The material is considered for its adsorbtion, cleansing abilities and chemical stability under the actual application conditions.

The main problem in microfiltration and ultrafiltration is flux decline because of concentration polarisation and fouling (Mulder, 1991). Therefore the choice of material is primarily concerned with the prevention of fouling and cleaning the membranes after fouling. Some of the polymers most frequently used as materials for micro filtration are:

- Polycarbonate.
- Polyvinylidene-flouride.
- Polytetrafluoroethylene.
- Polypropylene.
- Polyamide.
- Cellulose-esters.
- Polysulfone.
- Polyetherimide.

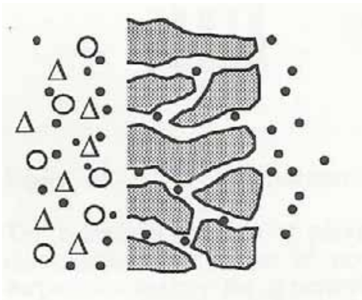

Fig. 22 Schematic drawing of a porous membrane
(Mulder, 1991)

5.8 Membrane types

Most of the membranes in use today are phase inversion membranes obtained by immersion precipitation. The polymer must be soluble in a solvent or solvent mixture. Basically, the membranes can be prepared in two configurations, flat and tubular. Flat membranes are used in plate and frame, and spiral wound systems. Tubular membranes are used in hollow fibre, capillary and tubular systems. Flat membranes are relatively simple to prepare and can be obtained by casting the polymer solution on a metal or polymer belt.

Tubular membranes are grouped into three types: -

- Hollow fibre membranes (diameter < 0.5 mm).
- Capillary membranes (diameter 0.5 - 5 mm).
- Tubular membranes (diameter < 5 mm).

Hollow fibres and capilliaries are prepared by wet, melt, or dry spinning. Tubular membranes are so large that the casting of the polymer solution has to be carried out on a supporting tubular material, for example, a non-woven polyester or a porous carbon tube.

A table listing the most common types of membrane configuration with their relative cost, turbulence promotion, advantages and disadvantages and applications is given below.

Table 8 Membrane configurations

(Stephenson et al, 2000)

Configuration	(m^2/m^3)	Cost	Turbulence Promotion	Applications
Pleated cartridge	800 - 1000	Low	Very poor	Dead end MF ED, UF, RO
Plate-and-frame	400 - 600	High	Fair	
Spiral-wound	800 - 1000	Low	Poor	RO, UF
Tubular	20 - 30	Very high	Very good	Cross-flow filtration High TSS waters
Capillary tube	600 - 1200	Low	Good	UF
Hollow fibre	5000 - 40000	Very low	Very poor	MF, RO

Configuration	Advantages	Disadvantages
Pleated cartridge	robust construction compact design	easily fouled cannot be cleaned
Plate-and-frame	can be dismantled for cleaning	complicated design cannot be back flushed
Spiral-wound	low energy cost robust and compact	not easily cleaned cannot be back flushed
Tubular	easily mechanically cleaned tolerates high TSS	high capital cost high membrane replacement cost
Capillary tube	characteristics between tubular and hollow fibre	
Hollow fibre	can be back flushed compact design tolerates high colloid levels	sensitive to pressure shocks

* The capillary tube is used in UF (the water flows from inside to outside the tubes).

* The hollow fibre is used in RO & MF (the water flows from outside to inside the tubes).

5.9 Membrane characterisation

Membrane need to be characterised to determine the membrane separation properties dependant upon pore size, pore distribution and free volume. Large discrepancies can occur between intrinsic membrane properties and actual membrane applications. Electron microscopy provides a technique for characterising microfiltration membranes.

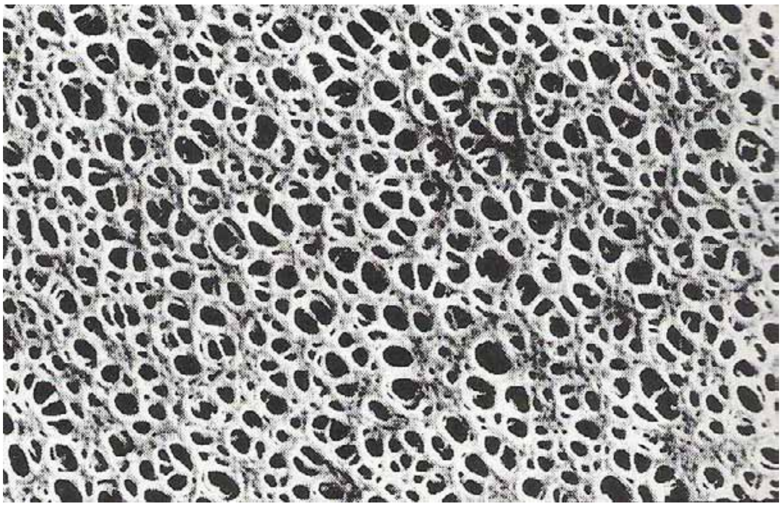

Fig. 23 Top surface of a porous organic polyetherimide membrane (magnification x 10,000) (Mulder, 1991)

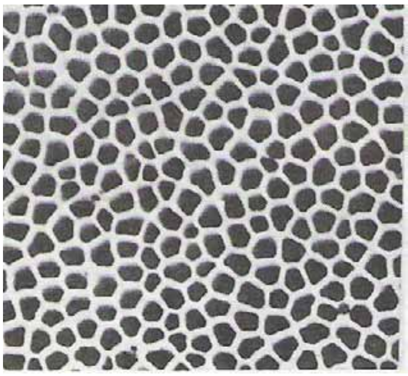

Fig. 24 Inorganic ceramic microfiltration membrane (Mulder, 1991)

The Bubble-point method provides a simple means of characterising the maximum pore size in a given membrane. The method essentially measures the pressure required to blow air through a liquid filled membrane. The relationship between pressure and pore radius is given by the LaPlace equation: -

$$r_p = 2 * \gamma * \cos\theta / \Delta P \qquad (1)$$

where r_p is the radius of a capillary shaped pore, and γ is the surface tension at the liquid/air interface. This method can only be used to measure the largest active pores in a given membrane and has become the standard technique used by suppliers to characterise their dead-end microfiltration membranes.

The Mercury intrusion method and the Permeation method are extensions of the Bubble-point method. The Mercury intrusion method determines both pore size and pore size distribution, using the same LaPlace equation, but $\cos\theta$ has a negative value, since mercury does not wet the membrane because its contact angle is greater than 90 degrees.

The Permeation method uses the Hagen-Poiseuille equation: -

$$J = (\varepsilon * r_p^2 * \Delta P) / (8 * \eta * \tau * \Delta x) \qquad (2)$$

where J is the water flux through the membrane, with ΔP being the pressure difference and Δx the film thickness. η is the liquid viscosity, ε is the membrane porosity and τ is the tortuosity factor.

5.10 Membrane processes

Basically, there are two process modes, they are, dead-end filtration and cross-flow filtration. In dead-end filtration the feed flow is along the membrane surface, so that the retained particles accumulate and form a type of cake layer at the membrane surface. The cake thickness increases with filtration time and consequently the permeation rate decreases. In cross-flow filtration the feed flow is along the membrane surface, so part of the retained solutes accumulate. The deposition of the solutes inside the pores of the membrane and at the membrane surface is called 'fouling'. Concentration polarisation, adsorption, gel layer formation, plugging of the pores are the cause of fouling, which results in the main problem encountered when microfiltration is applied - flux decline.

Flux decline occurs despite a proper choice of process mode, since it is an implicit part of the process, and the membranes must be cleaned periodically. This means that the choice of membrane material must be exhibit stability under the cleaning regime. Generally, the pure water flux through a membrane is directly proportional to the applied hydrostatic pressure, expressed as: -

$$J = \Delta P / (\eta * R_m) \qquad (3)$$

where R_m is the hydrostatic resistance of the membrane.

However, in microfiltration and ultrafiltration the flux decline is very severe with the process flux often being less than 5 per cent that of pure water.

CHAPTER 6 MBR AND CONVENTIONAL TREATMENT COMPARISONS

6.1 MBR and conventional treatment process comparisons

MBRs offer a system that competes very effectively with conventional treatment processes. The organic loading rates are generally higher than trickling filters, sequencing batch and conventional activated sludge process, due to shorter hydraulic retention time, but lower than BAFs, complete-mix and high rate ASP. A comparison of the organic loading rates and removal efficiencies of varying unit treatment processes is presented below.

Table 9 Organic loading rates for treatment processes (Gander et al., 2000)
(Till, 2001)

Reactor	Organic loading rate (kg BODm^-3/day)	HRT (hr)	Removal (%)
BAF			
Downflow	1.5 (COD)	1.3	93
Downflow	7.5	-	75
Upflow	4	-	>93
TF			
Low rate	0.08 - 0.4	-	80 - 90
Intermediate	0.24 - 0.48	-	50 - 70
High rate	0.48 - 0.96	-	65 - 85
ASP			
Sequencing Batch	0.08 - 0.24	12.0 - 50.0	85 - 95
Conventional	0.32 - 0.64	4.0 - 8.0	85 - 95
Complete Mix	0.8 - 1.92	3.0 - 5.0	85 - 95
High Rate Aeration	1.6 - 16	2.0 - 4.0	75 - 90
MBR			
Submerged: Plate and frame	0.39 - 0.7	7.6	99
Submerged: Hollow Fibre	0.005 - 0.11	8	98
Kubota	0.03 - 0.06	1	98 - 99

The advantages offered by membrane bioreactors over the conventional activated sludge process include a smaller footprint and reduced sludge production. Galil (2003) reports that biosolids, which had to be removed as excess sludge were characterised by a relatively low volatile to total suspended solids ratio - around 0.78. This could facilitate and lower the cost of biosolids treatment and handling.

Galil also reports that the MBR ability to develop and maintain a concentration of over 11,000 mg per litre of mixed liquor volatile suspended solids in the MBR bioreactor enabled an intensive bioprocess at relatively high cell residence time. Membrane bioreactors can be operated at mixed liquor suspended solids of up to 30,000 mg per litre and as sludge settling is not required, submerged membrane bioreactors can be up to 5 times smaller than a conventional activated sludge plant.

The high biomass concentration in the MBR tank allows complete breakdown of carbonaceous material and nitrification of municipal wastewater to be achieved within an average retention time of 3 hours.

The fact that clarification is achieved in a single filtration stage, in place of the conventional multi-stage process, also contributes to the smaller footprint. If additional denitrification is required for the system a second anoxic tank can be provided prior to the aeration tank with conventional recycle.

Sludge production is significantly reduced, compared to conventional ASP, as longer sludge ages are achievable (Till, 2001). A comparison between the sludge production of various processes is given below.

Table 10 Sludge production for various wastewater treatment processes
(Till, 2001)

Sludge production for various wastewater treatment processes	
Treatment process	**Sludge production (kg/kgBOD)**
Submerged MBR	0.0-0.3
Structured media biological aerated filter BAF)	0.15-0.25
Trickling filter	0.3-0.5
Conventional activated sludge	0.6
Granular media BAF	0.63-1.06

- The MBR system does not require flocs to be formed to remove the solids by settlement and therefore the biomass can operate at very high levels of MLSS, generally in order of 10,000 - 18,000 mg per litre.
- This high concentration enables a low tank volume and a long sludge age to be utilised, which reduces sludge production and allows for a small plant footprint. It allows for a 50 % reduction in aeration tank volume.

- Gravity filtration is possible and only modest power expense is required including the suction filtration. Membrane panels can be easily and quickly installed, and maintained by ascending or descending the units along guide rails. Membrane cleaning using chemicals is normally required only twice a year.

- The long sludge age process produces 35 % less sludge than conventional treatment process. Hence, less sludge handling and disposal cost. Since sewage sludge disposal contributes significantly to overall operating costs, there are significant potential benefits in reducing its production. Also, the sludge is highly stabilized (Till, 2001).

- Bacteria and most viruses can be removed by the process, dependant upon the pore size. Good disinfection capability, with significant bacterial and viral reductions achievable using UF and MF membranes. High and reliable quality of treated water is achieved. Consequently, the treated water can be reused for flush water for toilets and sprinkling water. Turbidity of the effluent is less than 0.2 NTU and suspended solids are less than 3 mg per litre. Effluent quality is consistently high and generally independent of the influent quality (Till, 2001).

- Longer retention of nitrifying bacteria within the bioreactor results in greater nitrification than in a conventional ASP (Galil, 2003). Denitrification can be achieved by utilizing a second anoxic vessel.

- Execution of work is easy, short work periods and low construction costs are possible because the whole system is simple and only a small amount of auxiliary equipment is required (refer to Appendix B Aquatec Maxcon product literature).

- Proven reliability and easy operation (Till, 2001).

A paper by Galil (2003) summarises the results obtained in a study based on a pilot plant, which compared a membrane biological reactor (MBR) process to the conventional activated sludge (ASP) process in the aerobic treatment of the effluent obtained from an anaerobic reactor. During the pilot operation period (about 90 days after achieving steady state) the MBR system provided steady operation performance, while the activated sludge produced effluent, which was characterised by oscillatory values. The results are tabulated below.

Table 11 Average results comparison

Galil (2003)

	Activated Sludge	**MBR**
Suspended solids (mg/L)	37	2.5
COD (mg/L)	204	129
BOD (mg/L)	83	7.1

The results were based on average values and indicated much lower levels of suspended solids in the MBR effluent. The total organic matter content was also substantially lower in the MBR effluent. The MBR enabled better nitrification and an intensive bioprocess at relatively high cell residence time.

Galil (2003) concludes that the results of this comparative study indicate that in the case of MBR there is no need for further treatment, while after activated sludge additional filtration will be required.

Another comparison is provided by Stephenson et al (2000), which has been taken from Cicek et al (1999), on the performance of an activated sludge plant with a sidestream MBR.

The comparison is shown in Table 12 below. The flocs in the MBR were shown to be significantly smaller and more active with a higher volatile fraction in the mixed liquor and a greater diversity of species especially in terms of free swimming bacteria. Enzyme activity was also seen to be higher in the MBR and this was attributed to washout in the activated sludge system.

Table 12 Performance comparison

(Stephenson et al, 2000)

Parameter	Activated Sludge	MBR
Sludge age (days)	20	30
COD removal (%)	94.5	99
DOC removal (%)	92.7	96.9
TSS removal (%)	60.9	99.9
Ammonical N removal (%)	98.9	99.2
Total P removal (%)	88.5	96,6
Sludge production (kg VSS/COD/day	0.22	0.27
Mean floc size (mm)	20	3.5

Stephenson et al (2000) qualify their statements by saying that the fundamental differences in the biology of an MBR compared to an activated sludge process are not yet clear, since a limited amount of information is available on the way in which descriptive variables such as the floc structure, respiration rate, species and off gas production are affected by the changes in operation.

6.2 MBR Benefits and Disadvantages

The Environment Protection Authority (1995) lists the following benefits: -

- Cost-effective - low life-cycle costs.
- Difficult contaminants degraded.
- High-quality effluent produced.
- Small footprint.
- Faster system start-ups.
- Long solids retention times.
- Minimal operating labour required.
- Minimal generation of biosludge.

Caetano et al (1995) list the advantages of the membrane process as: -

- Reduction of costs.
- Reduction of pollution.

- Recovery of high-value products.
- Recovery of energy.
- Increase of productivity.
- Improvement of quality.
- Creation of new products.
- Easy to expand the system.

The principal problem in the treatment of municipal wastewater, identified by Culp (1978), is membrane fouling, which can greatly reduce the capacity of the units. The primary foulants are believed to be colloidal material and designed organics. Fouling generally decreases with increasing degrees of wastewater pretreatment. RO units have achieved stable operation on wastewater without pretreatment by activated carbon absorption, but regular cleaning of the membranes is required.

6.2.1 Methods to reduce fouling

In practice, reduction of fouling can only reduce the need for cleaning. The frequency with which membranes need to be cleaned can be estimated from process optimisation. Cleaning can be hydraulic, mechanical and chemical. Some fouling reduction strategies are listed below: -

- Pretreatment methods, which include heat treatment, pH adjustment, addition of complexing agents, chlorination, adsorbtion onto active carbon, chemical clarification, and filtration.
- A change of membrane properties, for example, a narrow pore size can reduce fouling.
- Reduction of polarised concentration by increasing the flow velocities and using lower flux membranes.
- Turbulence promotion over the surface of the membrane.

6.2.2 Membrane malfunctioning

The most common geometries of membranes used are either spiral or tubular, because of the presence of suspended particles in wastewater.

Caetano et al (1995) provide some possible causes of malfunctioning of spiral wound membrane modules, which they suggest may be helpful in identifying problems with other modules. Preliminary diagnosis is made as a function of variation of rejection, flow and load loss. The principal effects, secondary effects and possible causes are presented below in tabular format.

Table 13 Module malfunctioning of spiral wound modules

(Caetano et al, 1995)

Principal effect	**Secondary effect**	**Possible causes**
Reduction of rejection	Increase of flow and reduction discharge loss	increase of temperature
		variation of pH
		chemical attack
		ageing
		membrane damage
		defective O-ring
		defective interconnector
		damaged central tube
		defective adhesive
	Flow reduction	defective brine seal
Row reduction	Increase of rejection and discharge losses	membrane compacting
	Reduction of rejection increase discharge losses	insufficient pretreatment
		low pressure
	Increase discharge losses	low temperature
		low pressure
	Reduction of rejection and load losses	increase feed concentration
Increase of flow	Reduction rejection load losses	high temperature
	Increase of rejection and reduction load losses	high pressure
	Increase of rejection and load losses	low feed concentration
Increase load losses	Increase of flow and rejection	high feed flowrate
	Reduction flow and rejection	deformed module
		high fouling
Reduction of load losses	Reduction flow and rejection	low feed flow rate

6.3 Commercial MBR systems (Refer to Appendices B, D & E))

The two main suppliers of MBR systems for wastewater treatment are Kubota (Japan) and Zenon (USA). Other suppliers are Degremont (France), Wehrle Werk (Germany), Hans Huber (Germany), Orelis Mitsui (Japan), Membratek (S. Africa), US Filter (USA).

Table 14 Summary of commercial MBRs
(Stephenson et al, 2000)

Manufacturer	Bioreactor	Type	Membrane	Flux (L/m^2/h)
Kubota	aerobic	submerged	flat panels	25
Zenon	aerobic	submerged		30
Orelis	aerobic	sidestream		100
USF	aerobic	submerged		40
Membratek	anaerobic	sidestream		40
WerhleWerk	aerobic	sidestream		100

Kubota uses a flat sheet membrane made of polyolefin with a non-woven cloth base giving a nominal pore size of 0.4 mm. Each membrane cartridge consists of solid acrylonitrile butadiene styrene (ABS) support plate with a spacer layer between it and an ultrasonically welded flat sheet membrane on both sides. The typical membrane cartridge (Type 510) has dimensions of 1.0 m (H) x 0.49 (W) x 6 mm thick - filtered water passes through to the interior of each membrane to an outlet nipple cast into the top of the support plate. Each cartridge provides an effective filtration area of 0.8 m^2.

The Kubota MBR operates with membrane treatment units submerged in the reactor in which the MLSS is maintained within the range of 15,000 to 20,000 mg per litre. The standard Kubota unit has a glass fibre reinforced plastic casing and consists of two sections. The upper section contains up to 150 membrane cartridges, each connected to a filtered effluent manifold with a gap of approximately 7 mm between cartridges. The lower section is a matching unit containing a coarse bubble diffuser. The lower section supports the upper section and directs the mixture of air bubbles and mixed liquor between the membrane cartridges in the upper section. This air-water mixture maintains an upward cross flow over the membrane surface of approximately 0.5 metres per second, minimising fouling of the membranes. The minimum air requirement is 10 litres per minute per cartridge.

The Kubota system operates by gravity, with a head of 1 to 1.5 metres above the membranes sufficient to drive permeate through the membranes. Grit removal and fine (2 - 3 mm) screening are pre-requisites prior to the MBR. The membrane flux for the Kubota system is approximately 20 litres / m^2 / h (submerged system at a TMP of ~ 0.1 bar).

Chemical cleaning of the membranes is required every three to six months using sodium hypochlorite and oxalic acid. Cleaning requires three litres of chemical solution per cartridge and the cleaning cycle takes up to two hours.

Kubota has a reference list of over 400 plants treating domestic and industrial wastewater, with most of the sites located in Japan. The Kubota plants range in size from systems to treat the equivalent of individual households to the 23,000 EP (5,800 m^3 per day ADWF) plant at Swanage in the south of England. The Kubota technology is utilised at the new MBR plant (2,000 EP) on Magnetic Island in Queensland (Till, 2001).

Zenon markets the ZenoGem system, based on the ZeeWeed membrane, which is a hollow fibre with an external diameter of 1.9 mm and a nominal pore size of 0.4 mm. The fibres are mounted on vertical frames into modules with filtered effluent passing into the centre of the fibre and extracted from both ends. The ZW 500 module is 2.0 m (H) x 0.7 m (W) x 0.2 m thick with 46 m^2 of filtration surface area. Cassettes are made up of 8 modules each. Air is supplied to the system by a combination of coarse bubble aerators integrated into the bottom header of modules, to gently agitate the membrane fibres and to keep the tank contents mixed, and by fine bubble aeration to supply the balance of the total biological oxygen demand.

The filtration capacity is in the range of 40 – 70 litres / m^2 / h under a driving transmembrane pressure of 10 - 50 kPa. This pressure is provided by the head of water over the membranes and by maintaining a negative pressure on the permeate side using conventional centrifugal pumps. Sludge wastage is claimed to be 1.5 to 2.0 per cent of the influent flow.

ZenoGem biological design parameters are: -

- MLSS 15,000 - 20,000 mg / L
- FM < 0.2 kg BOD/kg MLSS / day
- Volumetric Loading 1.8 - 5.7 kg BOD / m^3 / day
- HRT > 2 hours
- SRT > 15 days
- Flux 15 - 25 L /m^2 / h (TMP of approximately 0.5 bar)

In addition to the scouring action of the coarse bubble aeration, cleaning of the membranes to control fouling is provided by automatic pulses of backwashing with stored permeate and periodic in-situ membrane cleaning with a hypochlorite solution or other chemicals.

Zenon has a reference list of over 150 plants treating domestic and industrial wastewater (Till, 2001).

6.4 MBR Summary

The increased efficiencies, lower costs, and the higher quality standard of effluent production of the MBR systems, combined with community expectations for reduced environmental impact as set out in documents, such as 'The Environment Improvement Project-Western Treatment Plant: The Port Phillip Bay Environmental Study for the Discharge of Effluent', and reflected in government legislation, has meant that at many existing treatment plants, producing a standard secondary effluent (20 mg per litre BOD, 30 mg per litre SS), add-on processes have been constructed to achieve an equivalent tertiary effluent. The standard set by EPA Victoria for discharge to inland waters is given below.

Table 15 Standards for discharge to inland waters

(Environment Protection Authority, 1995)

Indicator	Unit	Median	90 percentile
BOD	mg/L	5	10
SS	mg/L	10	15
Ammonia - N	mg/L	2	5
Total N	mg/L	10	15
Total P	mg/L	0.5	1
Ecoli	orgs/100mL	200	1000

Commercial MBR systems have now been operational for many years and have proven both reliable and simple to operate. Membrane failure rates have proven to be low and increased scale and performance of the systems has resulted in reduced capital and operational costs. This, coupled with increased focus on water re-use and the need to achieve higher discharge standards, in order to satisfy legislation, means that the use of MBR technology is becoming a realistic option for advanced effluent treatment (also refer to Appendix F EPA Report 2003: Environmental Guidelines for the use of Reclaimed Water).

CHAPTER 7 MEMBRANE BIOREACTOR AT MAGNETIC ISLAND

7.1 Overview

Zenon, from Canada, are represented, in Australia, by John Thompson Pty. Ltd. Kubota is represented, in Australia, by AVL-Brindley, NSW (Natural Resources, Mines and Energy, Queensland Government, 2004).
AVL (Aguas Vie Ltd) is part of the Aquator Group of companies, formerly part of Wessex Water. This group of companies introduced membrane bioreactor plants to the United Kingdom, using Kubota submerged membranes and now have seven operating plants, with another thirteen under construction.

AVL provided process design, commissioning and process guarantee for the first Kubota MBR plant in Australia (at Picnic Bay, Magnetic Island). AVL joined with Brindley Engineering for future Kubota MBR plants in Australia (Enviro 2002 Convention and Exhibition, 2002). The membrane bioreactor plant is shown below.

Fig. 25 Membrane bioreactor plant
(Aquatec-Maxcon, 2004b)

The Aquator Group Ltd, is the world leader in the supply, operation and maintenance of submerged flat sheet membrane bioreactor technology, MBR Technology®. The company states that over a number of years the company has successfully treated effluents across diverse wastewater treatment requirements, including municipal sewage, industrial and commercial process applications in 900 plants worldwide. The company also states that MBR Technology® allows operators to maximise their discharge and reuse options, both in the municipal sector and across a range of manufacturing effluents, including but not limited to, pharmaceutical, paper and pulp, meat and vegetable processing and brewing and distilling.

This flat sheet membrane treatment disinfects wastewater in a compact single stage process. The discharged effluent is of a quality that ensures the operator meets and improves upon the most stringent discharge standards, typically producing < 5: 5: 5 BOD: SS: Ammonia, thus providing opportunities for water re-use. Flat sheet membrane bioreactors offer a high efficiency treatment from just a few cubic metres per day upwards (Melbourne Water, 2004b).

7.2 Municipal Sewage Processes

There are over 549 operational municipal sewage plants utilising the Kubota flat sheet submerged membrane process around the world, provided by the Aquator subsidiary, MBR Technology®.

The development of Kubota submerged membrane bioreactor technology was the result of a Japanese Government initiative to produce compact high quality effluent treatment plants. Since the first pilot plant using this technology in 1989, and the first commercial plant in 1991, over 900 plants have been installed worldwide. These treat a wide range of effluents, the principal application being sewage and sludge liquors, but also including industrial wastewater, manufacturing and processing wastewater, and greywater recycling for a wide range of re-use purposes. In the UK, a pilot trial has been run at Kingston Seymour since 1995. A full-scale plant has been operating successfully at Porlock since February 1998, treating a population waste of approximately 3,800 people. Swanage has been operating since September 2000 treating a population waste of approximately 28,000 people.

The process employs simple flat sheet membrane panels housed in GRP units and aerated by a coarse bubble system below each unit. A series of these membranes are submerged within an activated sludge treatment tank. The aeration necessary for treatment of the liquors also generates an upward crossflow over the membranes; this is essential to keep fouling of the filtration surface to a minimum. An advantage of this design is that the membrane panels are securely retained and do not touch or abrade each other, while the units also act as a flume to ensure effective tank mixing and even distribution of the biomass.

The membrane panels are manufactured with a pore size in the range of 0.1 to 0.4 microns, which in operation becomes covered by a dynamic layer of protein and cellular material. This further enhances the effectiveness of this filtration performance by providing an effective pore size of less than 0.01 microns, which is in the ultrafiltration range.

The membrane bioreactor treatment produces a high quality disinfected effluent. The raw sewage generally only requires screening and degritting prior to entering the membrane bioreactor tank. The process requires no primary or secondary settlement stages and no additional tertiary treatment or UV stages to achieve this very high disinfection quality typically better than 5: 5: 5 BOD: Suspended Solids: Ammonia.

Membrane bioreactor technology has a number of inherent advantages. The system does not require flocs to be formed to remove the solids by settlement and therefore the biomass can operate at very high levels of MLSS, generally in the order of 12,000 to 18,000 mg per litre, and as high as 22,000 mg per litre. This high concentration enables a low tank volume and a long sludge age to be utilised, which substantially reduces sludge production.

The hydraulic flow determines the required number of membrane units. Each membrane unit may contain up to 200 flat sheet membrane panels housed within a rectangular box, together with an integral aeration system in the bottom section of the unit. Treated effluent is removed from the membrane units using gravity head (typically 1 to 1.2 m), or a pumped suction operation can be utilised.

7.3 Operation and Maintenance

Operating experience of MBR process treatment plants has consistently shown an effluent of high quality, that has little dependence on variations in feed strength and is fully disinfected with bacteria and viruses reduced to below the EU limits for bathing water or recreational water standards.

By minimising the effect of fouling through controlled cross flow velocities over the membrane surface cleaning is required typically only twice per year using a backwash of high dilution dilute sodium hypochlorite solution into each membrane unit. The process is designed to run without supervision and by using high quality plastics and stainless steel, the membrane panels and units have long life expectancies in the most part beyond 10 years. The Aquator Group's comparison of the benefits of the MBR process compared to other processes is included below.

Table 16 Characteristics of the available wastewater treatment technologies (Aquator Group, 2004a)

	MBR	AST	Biofilter
Fast installation	✔		
Small footprint	✔		
Ease of operation	✔		✔
Low maintenance	✔		✔
No odour/vector attraction	✔		
High biomass concentration	✔		
High loading rates	✔		
Tolerates shock loading	✔	✔	
High & consistent effluent quality	✔		
Disinfection without UV/chemicals	✔		
Effluent suitable for agricultural or greywater reuse	✔		
Effluent suitable for discharge to sensitive waters	✔		

7.4 Magnetic Island Water Recycling

Fig. 26 Magnetic Island
(Magnetic Island Information, 2004)

Magnetic Island is located 8km north from the Townsville mainland. The island is surrounded by the waters of the Great Barrier Reef Marine Park, and is World Heritage listed. Most of the island is National Park. Four urbanised bays are suburbs of Townsville from which residents can commute to the mainland for work and school.

Magnetic Island does not have its own water source and residents are predominantly dependent on water supplied from mainland Townsville. Treated water is supplied through a 375 mm diameter high density polyethylene (HDPE) submarine pipeline that extends for 5.6 km from Pallarenda on the mainland to Bolger Bay reservoir. From Bolger Bay reservoir, water is distributed to other reservoirs on the island and finally to the island’s properties.

Fresh water, on the island, is also used to irrigate the Magnetic Island Golf Course. In order to reduce fresh water consumption and to avoid an ocean outfall, the recycling of treated wastewater for irrigation purposes became a sustainable and responsible option (Townsville City Council, 2004). Construction commenced as shown in Figure 27 below. The completed plant is shown in Figure 28.

Fig. 27 Magnetic Island Wastewater Treatment Plant during construction
(Aquator Group, 2004b)

Fig. 28 Magnetic Island Wastewater Treatment Plant
(Grundfos Pumps, September 2002)

The MBR system treats the island's sewage and wastewater, including that from nearby Nelly Bay pumping sub-station. Total project cost was about $6 million (Aquator Group, 2004b).

> *"The Magnetic Island plant, which required higher standards of treatment because of its position within the Great Barrier Reef World Heritage area, cost about three times that of present treatment plants, Cr Mooney said"* (Australian Academy of Technological Sciences and Engineering, 1988).

7.5 Technical information

Three Grundfos 50 kW submersible wastewater pumps are located at Nelly Bay - two installed side by side, while the third is on standby for installation as part of the backup system. Each of the installed pumps works on a demand basis pumping raw sewage to the main Picnic Bay plant, about a kilometre away. The pumps have a 54 metre head and operate at 39 litres per second. Drainage is via an overflow system into an emergency holding area.

The main Picnic Bay station services 2,000 people per day, and treats half a million litres of water every 24 hours. The plant uses 12 Grundfos pumps provided by Liquitech (Qld) Pty Ltd, of Townsville. Four Grundfos submersible wastewater single channel impeller pumps are used to assist in removing nitrogen from the sewage, and each has to handle water containing 1.5 percent solids. Two Grundfos submersible wastewater SuperVortex pumps are used with balancing tanks, lifting pre-treated sewage to a storage tank before pumping it back for further treatment.

During the treatment process, wastewater is pumped through the MBR, which filters out all bacteria and many viruses. The sludge sits in the bioreactor before being drawn off to a drying bed, and is eventually is transported to a dump as topsoil filling. After the sewage has been treated, two Grundfos submersible wastewater transfer pumps move the water to nearby Picnic Bay Golf Course for irrigation. All eight wastewater pumps are dry well mounted, work independently and are controlled by a logic computer (Grundfos Pumps, September 2002).

Paterson Flood Engineers Pty. Ltd. in MacKay, performed the detailed electrical and instrumentation design, preparation of electrical drawings, PLC Programming, Citect Configuration, factory testing of the PLC Panel, site testing and commissioning of the electrical installation and control system. In addition to this PFE supplied the PLC panel, Citect software and PC hardware.

Fig. 29 Electrical Control Panels
(Grundfos Pumps, September 2002)

- The control system included the following major items:
- B SLC505 Programmable Logic Controller (PLC) for Plant Control.
- Pentium computer running Citect 5.40 (sp.C) on Windows NT4
- Laptop computer running Citect 5.40 (sp.C) on Windows NT4 (sp.6) for remote access.
- Citect Manager license to allow access by third parties
- Paging alarm system connected to the control room computer.
- Telemetry unit to report alarms back to the CitiWater Townsville Depot.
- 100/10 Base-T Ethernet to connect the SCADA to the PLC and Networked Printer (Paterson Flood Engineers, 2002).

7.6 Design requirements

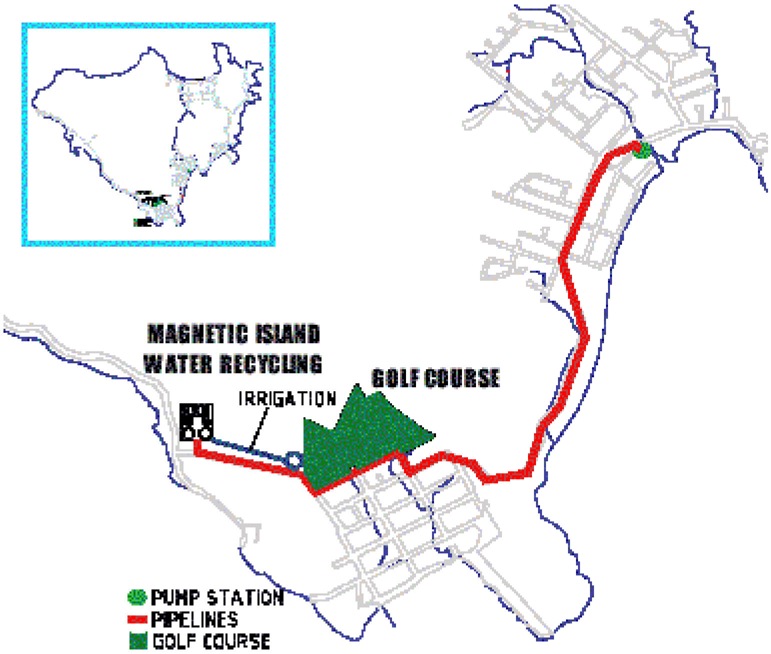

Fig. 30 The Magnetic Island Water Recovery Plant
(Townsville City Council, 2004)

The Magnetic Island Water Recovery Plant (refer figures 28 and 30) was commissioned in October 2002. The main contract was fulfilled by Aquatec-Maxcon Pty. Ltd. for CitiWater, Townsville. The complete wastewater treatment works includes inlet works (screening, grit and grease removal), four stage denitrification process, submerged membrane bioreactor and supplementary disinfection.

- Designed to treat effluent from an initial population of 2,000 people, and upgradeable to 8,000 people.
- 540 m^3 per day flow to full treatment.
- Very low noise production.
- Very low odour production.
- Very small plant footprint.

7.7 Process description

The process is designed around a modified four stage denitrification process incorporating Kubota submerged membranes.

Preliminary treatment is carried out by 3 mm fine screens and grit removal. The industrial stream is also passed through a DAF for grease reduction. Flow is balanced such that a maximum of 3 ADWF is allowed to pass to the membrane plant.

The treatment tank comprises four separate compartments: Primary anoxic, aerobic, secondary anoxic, and membrane basin.

Recycled sludge is sent to the aerobic zone and is subject to dissolved oxygen control. In this way the constant air supply to the membrane units is able to be incorporated into the conventional design.

Designed to operate at up to 18,000 mg per litre MLSS, the process is designed at an elevated sludge age (30 days not including membrane tank) so as to produce a stabilised, largely mineralised and easily treated waste sludge.

Waste sludge is dried in drying beds and collected leachate is sent back to the head of the plant.

Alum dosing is carried out prior to the membrane basins for the purpose of phosphorous reduction.

The permeate from the membranes is dosed with a small amount of hypochlorite to achieve further reduction in faecal coliforms.

The very high quality, fully disinfected effluent is suitable for a large number of re-use options. The design data and final wastewater characteristics are tabulated below.

Table 17 Final wastewater characteristics

(Townsville City Council, 2004)

Design data		**Final wastewater characteristics**	
Flow to full treatment	540 m³/d	BOD_5	< 5 mg/l
BOD load	135 kg/d	Suspended Solids	< 5 mg/l
Nitrogen load	24.3 kg/d	Ammonia	< 1 mg/L
Plant data		NH_3-N	< 1 mg/l
Aeration/Bioreactor volumes	115/202m^3	Total-Nitrogen	< 3 mg/l
1st Anoxic/2nd Anoxic volumes	41/75m^3	Total-Phoshorus	< 0.1 mg/l
No of membrane units	10x200 panels	Turbidity Faecal Coliforms pH	< 0.2 NTU < 5/100ml 6.5 - 8.0
NTU = Nephelometric Turbidity Unit BOD = Biochemical Oxygen Demand mg/L = Milligram per Litre			

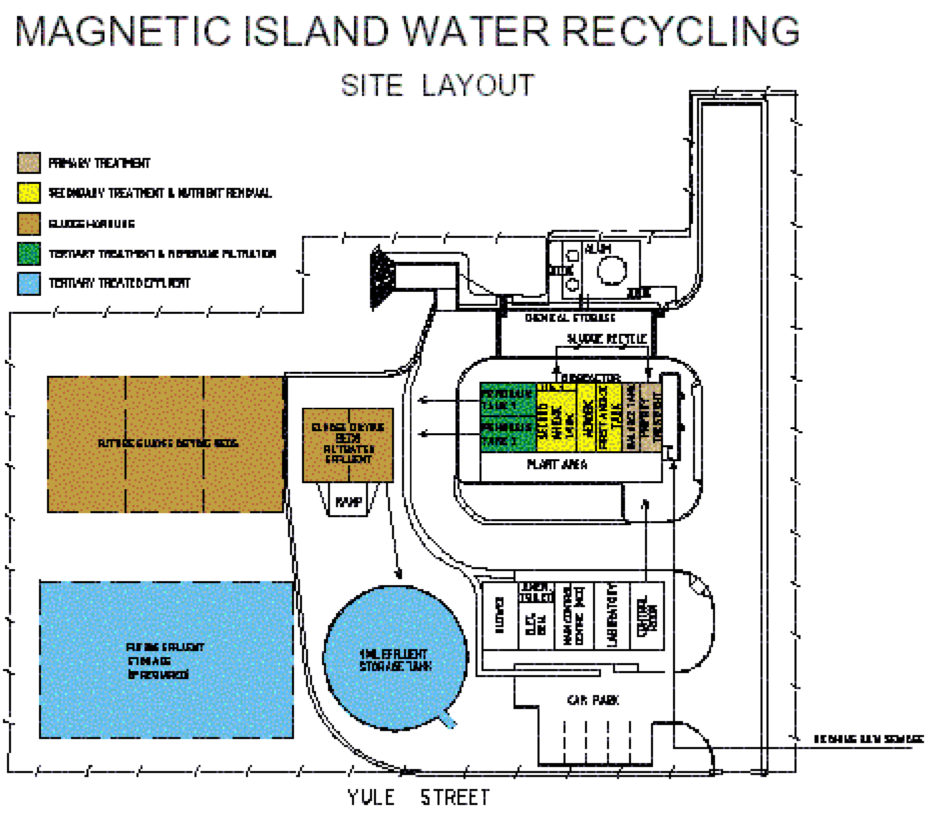

Fig. 31 Magnetic Island Water Recycling Plant - Site Layout

(Townsville City Council, 2004)

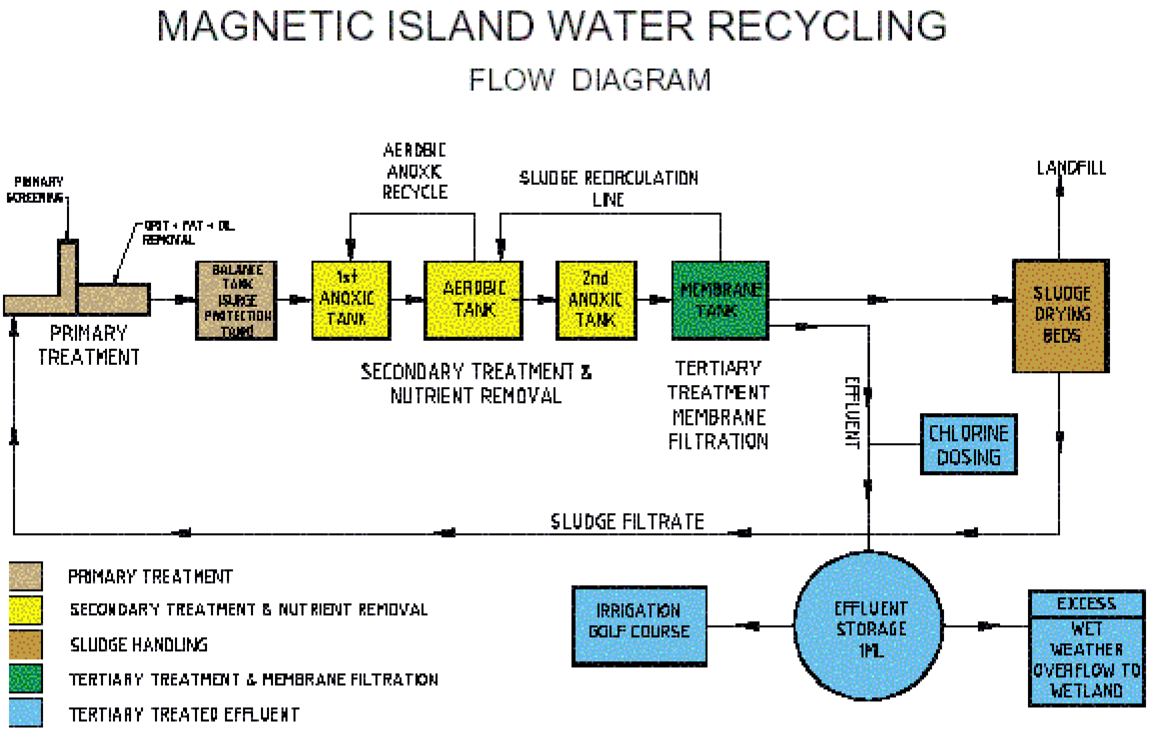

Fig. 32 Magnetic Island Water Recycling Plant – Flow diagram
(Townsville City Council, 2004)

7.8 Primary treatment

Wastewater entering MIWR flows through a screen where any solids above 3 mm in size are removed. Removing solids from the wastewater is the first step needed in order to protect mechanical equipment of downstream systems. The wastewater then moves on to a grit removal system where diffused air is used to separate grit particles from the wastewater. Diffused air separation is a process in which small air bubbles are injected into the wastewater to separate oils, grits and greases. Oils and greases float to the surface and these are skimmed off into a hopper which are then transported off site for treatment (refer to Appendix D - DAF Process).

7.9 Balance Tank

The balance tank is used when the flow to the plant becomes greater than five times the average dry weather flow. A flow controlled valve is closed slowly as the flow to the plant increases forcing primary treated wastewater into the balance tank. As the flow decreases to the plant, balance tank pumps lift the stored wastewater back into the plant as the flow control valve opens. This reduces and balances the hydraulic loading through the plant.

7.10 Secondary Nutrient Removal: Anoxic Tank 1

Anoxic Tank 1 receives primary treated wastewater and recycled activated sludge from the aerobic tank downstream. Anoxic Tank 1 is continually mixed by mechanical mixers. Autotrophic bacteria are produced in this tank by using the oxygen from nitrate and this process reduces nitrogen (a nutrient) levels. Excess nitrogen is often responsible for causing algae blooms around Australian rivers and coasts.

7.11 Secondary Nutrient Removal: Aerobic Tank 2

The activated sludge travels to Aerobic (contains oxygen) Tank 2 where dissolved oxygen is supplied to this tank by three variable frequency drive blowers. Dissolved oxygen levels are controlled by computer. Dissolved oxygen is the concentration of oxygen in the wastewater and is measured in milligrams per litre (mg / L). Measuring and maintaining the levels of dissolved oxygen is an important activity. It ensures the activity of the heterotrophic and autotrophic bacteria that help to reduce organic compounds and nutrients (such as ammonia, nitrate and phosphorus) resulting in a cleaner wastewater.

Excess phosphorus is reduced by the dosing of aluminium sulphate. Low pH levels can be corrected by caustic dosing. Protozoa and more advanced forms of life are present and they feed on the heterotrophic and autotrophic bacteria. This process reduces then pollutant load of the raw wastewater, which results in a cleaner wastewater.

Anoxic Tank 2 is designed to reduce nitrogen level and is only mechanically mixed, not aerated. The autotrophic bacteria further consume all the remaining available oxygen from the nitrate, thus reducing the total nitrogen discharged to levels approaching the lowest levels achieved anywhere in the world.

7.12 Submerged membrane filtration

This is the next and most advanced step in the wastewater treatment process. The submerged membrane tanks operate with very high solids levels (range 15 - 20,000 mg per litre), well above the levels of a normal activated sludge system. The size of the pores in the submerged membrane are 0.1 microns.

Sludge is held in this system for 30 days and the bio-flora growth on the membrane enhances the membrane performance to less than 0.1 microns. The bio-flora is kept to a fine film by the scouring action of air and activated sludge flowing upwards past the membrane. The treated wastewater passes through 1120 m^2 of membrane plates. This permeate (wastewater treated by the membrane process) is then chlorinated and stored in a one million litre tank.

7.13 Reuse/recycle

The high quality wastewater produced in this treatment plant is a valuable resource and is then pumped to the Magnetic Island Golf Course, for irrigation purposes. At the golf course, this permeate is pumped to an operational tank and then to an irrigation system that was installed using the latest technology in effluent application and computerised control.

Treating the wastewater produced in Magnetic Island to world's best standards and recycling it for irrigation purposes at the golf course has many advantages: -

- Enhancement of the use and presentation of the golf course.
- Conservation of the fresh treated water that is delivered to Magnetic Island.
- Avoidance of an ocean outfall discharge, thus maintaining the health of the Marine Park (Townsville City Council, 2004).

7.14 On-site water recycling

It has been known for some time that biological treatment can be a highly cost-effective approach to the treatment of difficult aqueous wastes, particularly where at-source treatment can be applied (Pitre, undated).

Pitre (undated) cites several examples to demonstrate that high performance biological treatment systems using advanced microbiology can achieve cost-effective wastewater and groundwater compliance, in efficient and compact systems.

- An MBR system used to pretreat landfill leachates was shipped to a facility from the surrounding area. The effluent from the pretreatment system was then processed at the existing municipal wastewater treatment plant. The design influent flow to the MBR system is 1,800,000 litres per day with a chemical oxygen demand (COD) of 10,000 mg per litre. The footprint of the system is approximately 630 m^2.

- The second MBR system is a mobile publicly owned treatment works, capable of treating 360,000 litres per day with a BOD of 625 mg per litre. This system has phosphorous removal and disinfection capabilities built in. The footprint for this system is approximately 60m^2.

- An MBR system designed for a petrochemical company to treat three high-strength industrial wastes, including alcohols and sulfur-containing compounds. One waste stream consisted of approximately 60 percent isopropanol by weight. The other streams contained light hydrocarbons and organic sulfides. The three streams treated accounted for less than 2 percent of the plant's hydraulic waste load, but over 70 percent of the organic waste load. The influent COD to the MBR was 25,000 mg per litre. Removal efficiencies averaged 90 to 95 percent and allowed the plant to stay within regulatory limits economically.

Finally, comparing the final wastewater characteristics of the MBR process at Magnetic Island and the Activated Sludge Plant at Werribee, we can see that the faecal coliforms are virtually non existent in the MBR final wastewater but still quite numerous in the ASP treated wastewater. The MBR is below the predicted limit of 5: 5: 5 BOD: Suspended Solids: Ammonia, but the ASP is in double digit figures for the same criteria. This can be seen clearly in the figure below.

Table 18 Comparison of the final wastewater characteristics of a MBR and an ASP

	MBR (mg/L)	**ASP (mg/L)**
Biochemical Oxygen Demand	< 5	< = 20
Suspended Solids	< 5	< = 30
Ammonia	< 1	< = 3
Nitrogen	< 3	< = 15
Phosphorus	< 0.1	< = 10
Faecal coliforms	< 0.05/mL	< = 1000/mL

Given that the cost of a membrane reactor is directly proportional to the cost of the membrane, whilst the conventional activated sludge plant exhibits economies of scale, Pitre (undated) concludes by saying that now, more than ever before, installation of at-source treatment systems is a technically feasible, cost-effective alternative to the expansion of existing, or construction of new, central treatment facilities. Figure 33 below gives a view of the way in which that alternative might work.

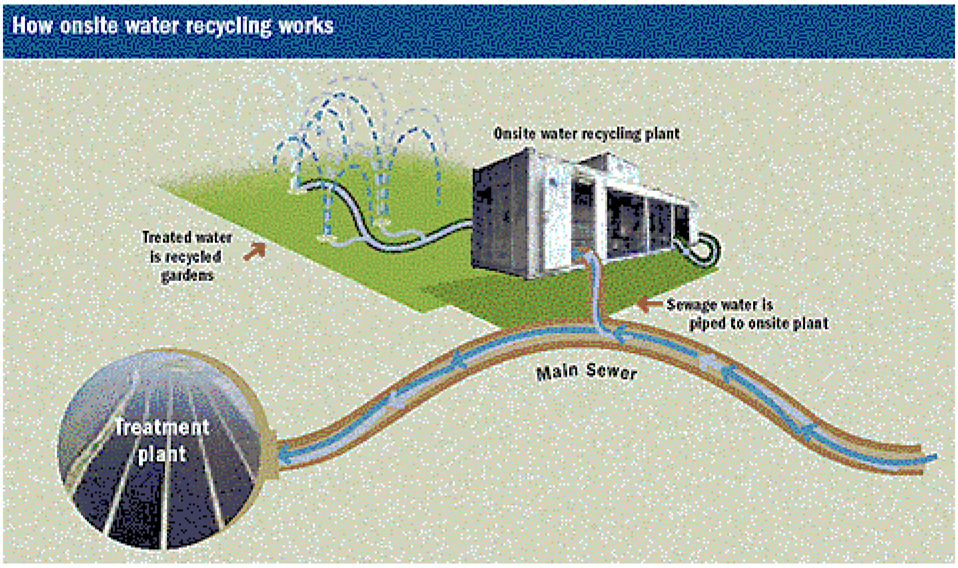

Fig. 33 How onsite water recycling works
(Melbourne Water, 2004b)

CHAPTER 8 CONCLUSION

Study of the effluent quality produced by conventional secondary treatment processes reveals that such treatment methods do not remove many pollutants - which may create a pollution problem, or prevent reuse of the effluent. Should the presence of materials found in secondary effluent be objectionable because of the need to reuse the water or to alleviate pollution, a selection must be made from among the appropriate advanced waste treatment unit processes.

Some of the many factors to be considered when designing an advanced waste treatment facility as mentioned by Culp (1978) are: -

- The disposition and use of the final effluent.
- The related requirements for effluent quality.
- The nature of the material to be removed in order to achieve the required quality.
- The problems associated with handling of the solids or waste liquids generated in the liquid treatment process.
- The potential for recovery and reuse of coagulants or other materials used in the treatment processes.
- The limitations imposed by the sewage collection system and available plant sites.
- The potential for creating air or land pollution in the process of treating wastewater.
- The demand for energy and other consumable resources.
- Overall economic feasibility.

This project has looked at the membrane bioreactor in particular, and comparisons have been shown between the different types of membranes, and membrane reactors. The types which are commercially available have been listed, along with their particular design features and performance characteristics. This has, in turn, highlighted the advantages and limitations of the membrane bioreactor.

The comparison between the conventional processes and the membrane bioreactor has shown that the use of varying combinations of different processes for different applications in varying environments is the best option economically, socially, environmentally and sustainably.

The unit processes now being used for advanced waste treatment have generally been used for various industrial purposes, and adapted to waste treatment plant design as the need for higher effluent quality has developed.

The handling of the solids or waste liquids, generated by treatment of the liquid phase, is of major importance, since the residues of the waste treatment cannot be discharged into a useable source if a net gain is to be achieved by the advanced waste treatment process. In many instances, the disposal of these residues may be the major factor governing the selection of the liquid treatment process.

High performance biological treatment systems using advanced microbiology, providing efficient and compact systems, can achieve cost effective wastewater regulatory compliance.

The installation of at-source treatment systems present alternatives to the expansion of existing treatment facilities and the construction of larger treatment facilities. The consequences and costs of the production of the initial wastewater, and the benefits and liabilities of the waste products recovered, can be more closely related to, and accessed by, those generating the wastewater, at or close to the treatment plant.

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APPENDIX A

APPENDIX A PROJECT SPECIFICATION

Aim

To determine, by investigation, the characteristics and operational properties of the membrane bioreactor.

Scope

- The identification of the stringent processes used to select an MBR plant.
- A discussion of the construction, commissioning and operation of an MBR plant.
- A comparison with the activated sludge system (and possibly other systems) in treating wastewater.

The plants that will be used as primary examples are: -

- The membrane bioreactor (MBR) installed at Picnic Bay, Magnetic Island.
- Land treatment plant at Werribee, Melbourne.

The focus and the emphasis for the project will be the membrane bioreactor: -

- The types available.
- Particular design features.
- Operation and applications.
- Advantages and/or limitations.
- The science and the technology.
- Performance.

Tasks

- Literature review
- The tasks involved are of an investigative and evaluative nature, which will be applied primarily to previously written material and data concerning the technologies and methods used in an MBR plant.
- The companies involved in the planning, commissioning, operation, and maintenance of the plants will be approached for assistance in providing additional information.

APPENDIX B

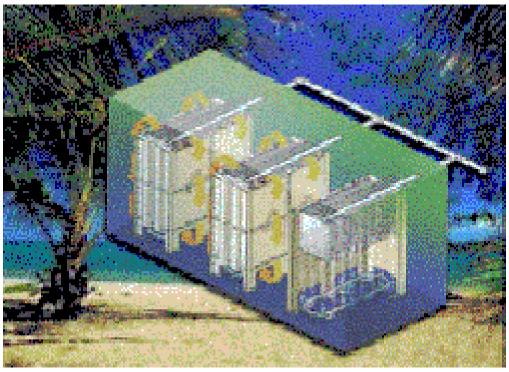
APPENDIX B Aquatec Submerged MBR

AQUATEC-MAXCON PTY LTD PRODUCT LITERATURE

AQUA-MBR Submerged Membrane Bioreactor

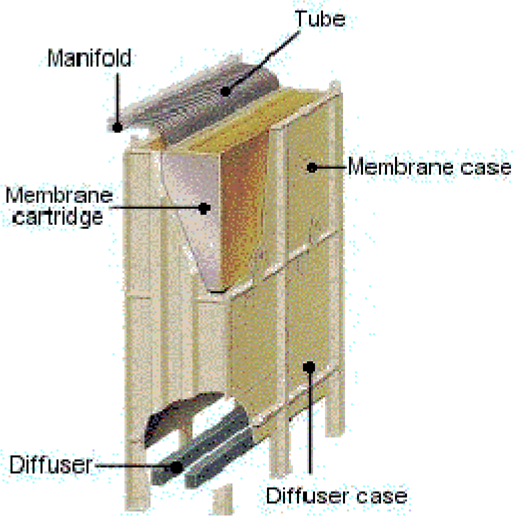
Product description

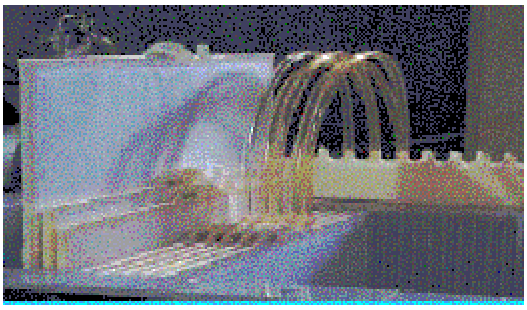
Aqua-MBR opens a new era in sewage treatment processing.
Developed as a small foot print, energy efficient treatment system with excellent effluent quality for reuse and less sludge production.
The sedimentation tank of a conventional activated treatment system is replaced by a submerged type solid-liquid separation membrane.

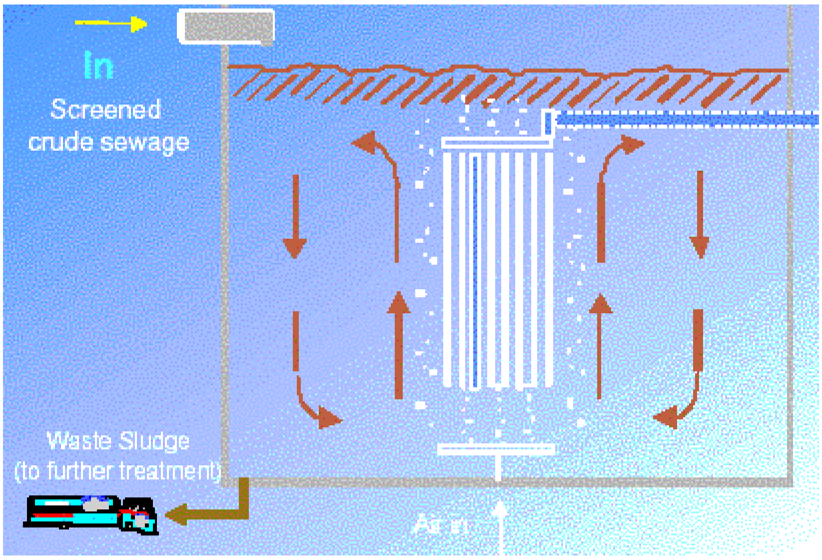


Aqua-MBR utilises a robust flat sheet submerged membrane unit, which has a long life & less cleaning requirement than other membranes

Kubota Flat Sheet Membrane Panels





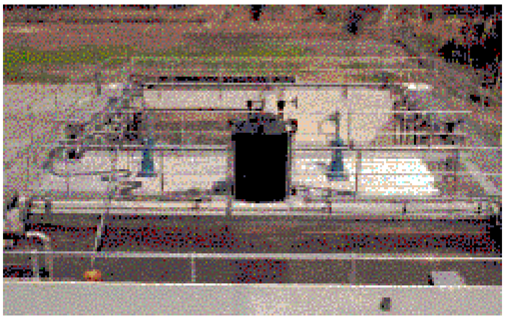


Design features

The submerged unit comprises cartridges with fine porous membranes fixed to both sides of a supporting plate and tubes for removing treated water from the cartridges.
The membrane case for storing a large number of membrane cartridges, as well as diffuser and diffuser case at the lower portion.
The membrane cartridge can be removed one by one for easy inspection and replacement.
. Gravity flow system
No requirement for vacuum abstraction
. Robust design & minimal operation intervention
. No requirement for regular cleaning-typically twice yearly only
No pulsed backwash system required
Not clogged by hairs or fibers
Rigid design prevents damage through fatigue-membranes do not abrade each other
Modular designs for easy upgrade

Main application

Solid-liquid separation for high concentration activated sludge treatment
Domestic wastewater treatment
Wastewater reuse systems
Sewage treatment
Rural wastewater treatment
Industrial wastewater treatment



Design advantages

1. Compact Plant

Aqua-MBR has a number of inherent advantages. The system does not require flocs to be formed to remove the solids by settlement and therefore the biomass can operate at very high levels of MLSS, generally in order of 10,000 -18,000mg/L.

This high concentration enables a low tank volume and a long sludge age to be utilised, which reduces sludge production and allows for a small plant footprint. It allows for a 50% reduction in aeration tank volume.

2. Energy Saving Operation & Easy Maintenance Control

Gravity filtration is possible and only modest power expense is required including the suction filtration. The submerged membrane can be easily & quickly installed and maintained by ascending or descending the units along guide rails. Membrane cleaning using chemicals is normally required only twice a year.

3. Less Excess Sludge Production

The long sludge age process produces 35% less sludge than conventional treatment process. Hence, less sludge handling and disposal cost. Also, the sludge is highly stabilized.

4. Reliable Quality of Treated Water because of Membrane Separation

Because of the small pore size of the membrane (.01 micron effective pore size) bacteria and most viruses are removed by the process. High and reliable quality of treated water is achieved. Consequently, the treated water is able to be reused for flush water for toilets and sprinkling water. Turbidity of the effluent is less than 0.2 NTU and suspended solids are less than 3mg/l.

5. Short Work Period and Low Cost in Construction

Execution of work is easy, short work periods and low construction costs are possible because the whole system is simple and only a small amount of auxiliary equipment is required.

APPENDIX C

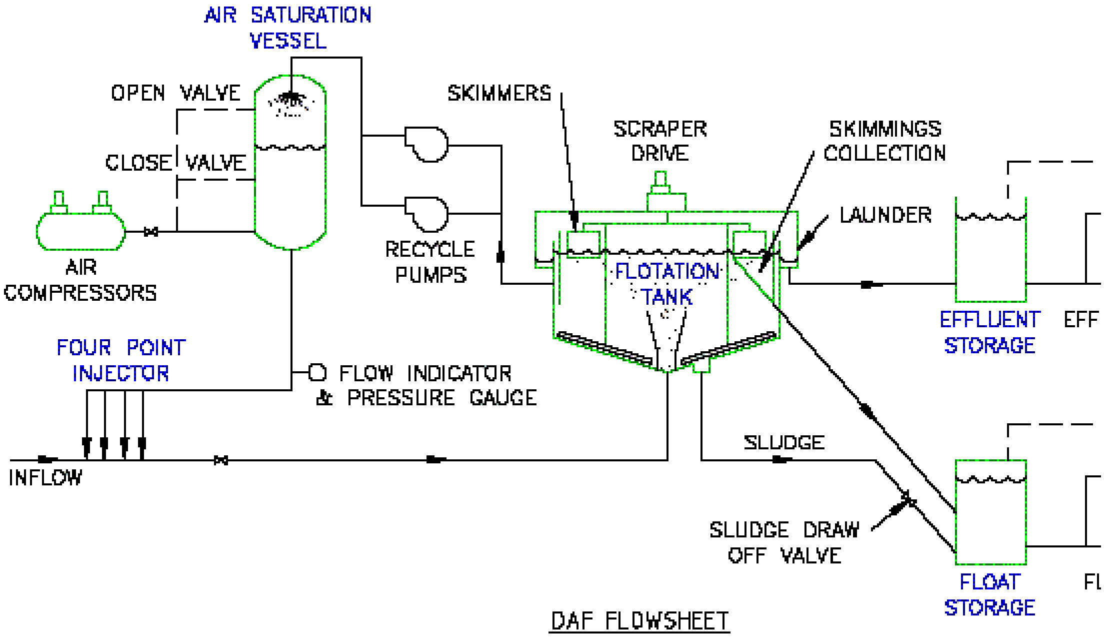
APPENDIX C Dissolved Air Flotation

AQUATEC-MAXCON PTY LTD PRODUCT LITERATURE

DISSOLVED AIR FLOTATION, "DAF"

Superior Water-Solids Separation

DAF is a process by which small, micronsize bubbles are made to attach to suspended material in water and carry the solids to the liquid surface. Once at the surface the solids are mechanically skimmed to produce a thickened sludge of 2 to 5%. Similarly, mixed liquors and sludges can also be thickened.
The process operates at higher hydraulic and solids loadings than gravity devices, is space efficient and particularly suitable for a wide range of municipal biological sludges, industrial wastewaters, and oily material.
Aquatec-Maxcon Can Offer Tailored DAF Designs to Suit Particular
Industrial and Municipal Applications



Design Advantages

Mechanical simplicity through a bridge mounted drive unit for collection of float and bottom floc, thus avoiding greasy chain collectors and screw conveyors found in other designs.
Simple on/off controls throughout to ensure ease of operation and to avoid unnecessary complex control loops
Fabrication can be in steel, concrete, or composite materials
Over 99% solids capture is regularly obtained even on thickening applications.
Standard circular design provides minimum hydraulic gradient for optimum solids separation and enables a single drive unit for both float and floc scrapers
Design incorporates ability to build substantial float layers above the liquid level to enable gravity drainage and maximum float solids content
Thickening of Waste Activated Sludge to 5% Without Polymer Addition is possible
Design Features

Aquatec-Maxcon uses a high efficiency saturator to dissolve air into a portion of the wastewater at a pressure of 300 to 600 kPa. This portion is then recombined with the main wastewater under pressure

A valve subsequently reduces the pressure to near atmospheric, upon which an effervescence is induced in the wastewater by the formation of small bubbles of the order of 20 to 50 µm in diameter

These bubbles attach themselves to suspended solids and transport the solids to the surface, forming buoyant rafts or 'float'. The depth of this float is controlled by adjustable height skimmers

In thickening applications, the float is allowed to form a thick raft of optimum depth (through adjustment) to enable gravity drainage of the liquid formaximum performance

Aquatec-Maxcon Pty. Ltd.
QLD: 119 Toongarra Road, NSW: 1st Floor 221 Eastern Valley Way
Ipswich QLD Australia 4305 Middle Cove, NSW Australia 2068
TELEPHONE: (61) 7 3813 7100 TELEPHONE (61) 2 9958 8029
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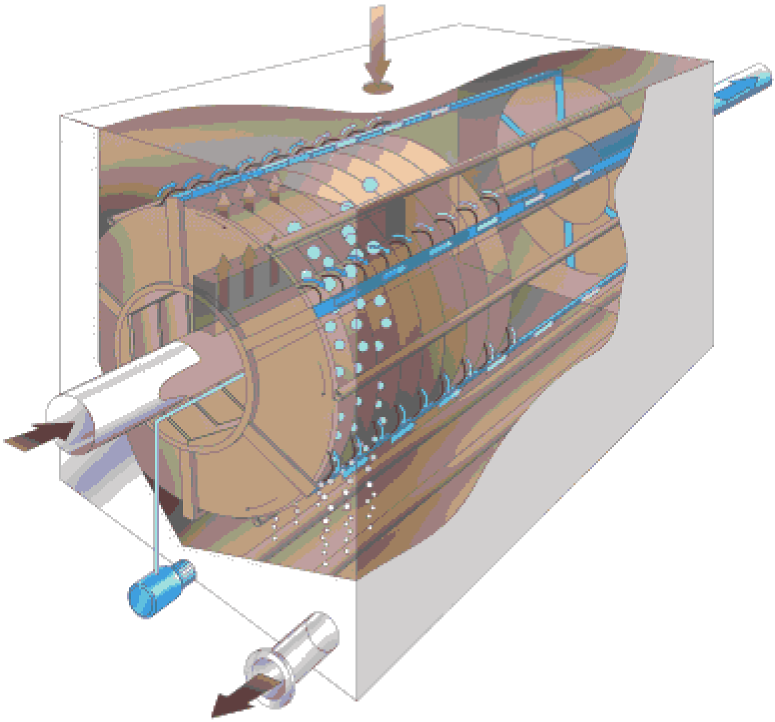
EMAIL: aquateci@gil.com.au EMAIL: aquatecs@aquatec.com.au
Web: www.aquatecmaxcon.com.au

APPENDIX D

APPENDIX D HUBER Membrane Bioreactor

HUBER - Membrane Bioreactor

The future-oriented solution for ever increasing requirements in wastewater treatment
For a maximum effluent quality



The situation
Technical progress in the field of municipal wastewater treatment, which includes removal of eutrophicating pollution loads, has in the past few years significantly improved the process flow of sewage treatment plants.
But little attention had been paid to the high number of disease-causing germs in the sewage treatment plant outlet.
To prevent the risk, micro and ultrafiltration combined with the activated sludge process, has turned out in recent years to be the suitable method to minimize the effluent load and retain at the same time pathogenic germs. Tightening discharge standards for sewage treatment effluents can thus be met, without the need for the "classic" aeration and secondary clarification tanks or filtration and desinfection plants.
The innovative Huber membrane technology offers you the following benefits:
Optimum effluent quality: free of solids, bacteria and germs
Allows for reuse of used water
Complies with the latest legal EC standards for bathing waters
Improves the performance of existing sewage treatment plants
Suitable for municipal and industrial applications
Hans Huber AG, Maschinen-und Anlagenbau, Industriepark Erasbach A1, D-92334 Berching Phone: +49-8462-201-0, Fax: +49-8462-201-810, email: info@huber.de
http://www.hanshuberag.com/produktee/membrane.htm

APPENDIX E

APPENDIX E ZeeWeed Filter Applications

ZeeWeed® 500 Target Applications
The membranes are versatile and can be used in both water treatment and wastewater treatment applications. They are intended for applications with medium to high suspended solids concentrations. The target applications have been divided into two groups:
1) Water Treatment (Direct Filtration):
Municipal drinking water treatment: membrane filtration of surface or ground water to produce potable water. Membrane filtration can also be combined with: enhanced coagulation (for organics and arsenic removal); chemical oxidation (for iron and manganese removal); powdered activated carbon addition (for taste and order removal) to achieve particular effluent requirements
Reverse osmosis (RO) pre-treatment: membrane filtration of surface water or ground water to reduce SDI of RO feed
Tertiary treatment: membrane filtration of secondary effluent from wastewater processes for recycle/reuse or simply to ensure optimum quality effluent is continuously discharged
2) Wastewater Treatment (Membrane Bioreactor Systems):
Municipal/industrial wastewater treatment: combining membrane filtration with a conventional activated sludge process to treat a variety of municipal or industrial wastewaters.
Shipboard wastewater treatment: for wastewater treatment on a variety of ocean-going vessels.
Commercial or private development wastewater treatment: for property owners who wish to treat their wastewater on the premises (typically because they cannot be connected to a municipal sewer because of capacity limitations or distance).
In wastewater treatment, the combination of membrane filtration and biological treatment is otherwise known as "membrane bioreactors" and is offered by ZENON as the ZeeWeed® MBR Membrane Bioreactor process. In this process, the ZeeWeed® membrane serves to replace the clarifier in a wastewater treatment system. The benefits of substituting a ZeeWeed® membrane for the clarifier are significant and include:
Tertiary quality effluent is produced without extra equipment since the membrane is an absolute barrier to suspended and colloidal solids
Capacity of existing wastewater treatment plants can be increased without requiring more tanks as the MLSS in the activated sludge tank can be increased to 10,000 - 12,000 mg/l
Nutrient removal is improved because of the effective retention of suspended solids by the membrane
The membrane is a reinforced fibre with a nominal pore size of 0.04 µm.
The membrane module is the building block of the system. An individual membrane module is the smallest replaceable unit within a ZeeWeed® filtration system. The ZeeWeed® 500 membrane module consists of hundreds of membrane fibres oriented vertically between two headers. The hollow fibres are slightly longer than the distance between the top and bottom headers and this allows them to move when aerated. It is the air that bubbles up between the fibres that scours the fibres and continuously removes solids from the surface of the membrane.
Zenon Environmental, http://www.zenon.com/products/500.shtml.

APPENDIX F

APPENDIX F EPA Report: Environmental Guidelines for the use of Reclaimed Water

EPA Report: Environmental Guidelines for the use of Reclaimed Water

The four microbiological classes that determine the permissible end uses are:
Class A: <10 thermotolerant coliforms per 100mL (median value). Suitable for high contact end uses eg residential garden watering
Class B: <100 thermotolerant coliforms per 100mL (median value). Suitable for medium contact uses eg irrigation of pasture for dairy animals
Class C: <1000 thermotolerant coliforms per 100mL (median value). Suitable for low contact uses eg irrigation of open spaces with public access controls
Class D: <10,000 thermotolerant coliforms per 100mL (median value). Suitable for non-human food chain uses (eg cotton growing).

Table 2. Microbiological controls for specific irrigation methods of food crops

Reuse category - type of crop	Application method	Harvesting controls	Microbiological quality
Raw human food crops in direct contact with reclaimed water			
Large surface area crops grown on the ground and consumed raw (eg broccoli, cabbage, cauliflower, lettuce, celery)	Spray , flood, drip, furrow, sub-surface	None	Class A
Root crops consumed raw (eg carrots, onions)	Spray, drip, flood, furrow, sub-surface	None	Class A
Raw human food crops not in direct contact with reclaimed water or crops sold to consumers cooked (>70℃ for 2 minutes) or commercially processed.			
Crops without ground contact (eg tomatoes, peas, beans, capsicums, non-citrus orchard fruit, non-wine grapes)	Spray (direct contact) Flood Drip, furrow Sub-surface	None Dropped produce not to be harvested Dropped produce not to be harvested None	Class A Class B Class C Class C
Crops without ground contact and with skin that is removed before consumption	Spray	Produce should not be wet from irrigation with reclaimed water	Class B (if crops are commercially processed or

(eg citrus, nuts)	Flood, drip, furrow, sub-surface	when harvested Dropped citrus not to be harvested	cooked at >70℃ for 2 minutes, then Class C can be used) Class C
Crops with ground contact and skin that is removed before consumption (eg melons)	Spray Flood, drip, furrow Sub-surface	Produce should not be wet from irrigation with reclaimed water when harvested Produce should not be wet from irrigation with reclaimed water when harvested None	Class B (if crops are commercially processed or cooked >70℃ for 2 minutes - Class C can be used) Class C Class C

Root crops processed before consumption (eg potatoes, beetroot)	Spray, flood, drip, furrow, sub-surface	None	Class C
Surface crops processed before consumption (eg brussel sprouts, pumpkins, cereals, grapes for wine making)	Spray, flood, drip, furrow, sub-surface		Class C
Non-food crops			
Crops not for human consumption, silviculture, turf growing	Any	Prohibit public access to area Dry or ensile turf before harvesting. Dry silviculture crops before use	Class D
Pasture and fodder for dairy animals			
Irrigation of pasture and fodder for dairy animals	Any	Withholding period of 4 hours before pasture use for dairy animals; alternatively dry or ensile fodder before use Withholding period	Class B Class C

		of 5 days before pasture use for dairy animals; alternatively dry or ensile fodder before use	
Pasture and fodder (for grazing animals except pigs and dairy animals)			
Irrigation of pasture and fodder for non-dairy animals		Withholding period of 4 hours before pasture use for non-dairy animals; alternatively dry or ensile fodder before use	Class C

Table 3. Potential quality concerns for industrial reuse

Quality	Problem
Microbiological quality	Risk to health of workers and the public
Chemical quality (eg ammonia, calcium, magnesium, silica, iron)	Corrosion of pipes and machinery, scale formation, foaming etc
Physical quality (eg suspended solids)	Solids deposition, fouling, blockages
Nutrients (eg phosphorus and nitrogen)	Slime formation, microbial growth