final report

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Dissinfection of effluent from meat processing works

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Environment

Final Reports

1. *Disinfection of Effluent from Meat Processing*

2. *Nutrient Removal from Meat Processing Wastewaters*

3. *Phosphorus Removal from Meat Processing Wastewaters*

4. *Technical Report on Continuous Anaerobic Pond Desludging*

<u>NOTE:</u>

(1) Find our four Environmental Reports as outcomes of previously approved project

(2) A brief overview of each report will be given by MLA technical staff and discussion held with Reseacrh Committees to determine appropriate next steps

MEAT & LIVESTOCK AUSTRALIA

AMPC

TABLE OF CONTENTS

ABBREVIATIONS

ANZECC	Australian & New Zealand Environment & Conservation Council.
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AS	Activated Sludge - a form of biological wastewater treatment.
BNR	Biological Nutrient Removal - specialised form of activated sludge process designed to remove Nitrogen and Phosphorus.
BOD	Biological Oxygen Demand - the quantity of oxygen required for the biological treatment of a wastewater.
Cl_2	chemical formula for Chlorine
CMF	Continuous Micro-Filtration - a membrane technology used to separate pollutants from water and wastewater.
COD	Chemical Oxygen Demand - the quantity of oxygen required for the chemical oxidation of a wastewater.
e^-	electron
EPA	Environment(al) Protection Authority/Agency.
g	gram - measure of mass.
H_2O	chemical formula for water
HOCl	chemical formula for Hypochlorous Acid
HRT	Hydraulic retention time - the time taken for a flow to pass through a tank, lagoon or treatment process.
kg	kilogram - measure of mass in thousands of grams.
kL	kilolitre - measure of volume in thousands of litres.
L	litre - measure of volume
L/s	litres per second - measure of flow rate.
mg/L	milligram per litre - measure of concentration.
m	metre - measure of length/distance.
m^3	cubic metres- measure of volume.
MIRINZ	Meat Industry Research Institute of New Zealand.
mg	milligram- measure of mass in thousandths of a gram.
mL	millilitre- measure of volume in thousandths of a litre.
ML	mega litre - measure of volume in millions of litres.
MLA	Meat & Livestock Australia.
ML/day	megalitre per day - measure of flow rate in millions of litres per day.
NH_3-N	chemical formula for Ammonia Nitrogen.
NHMRC	National Health and Medical Research Council.
OCl^-	chemical formula for Hypochlorite.
O_2	chemical formula for Oxygen.
O_3	chemical formula for Ozone.
pH	a measure of hydrogen ions in solution.
PO_4-P	chemical formula for Phosphate.
RO	Reverse Osmosis - a membrane technology used to separate pollutants from water and wastewater.
SBR	Sequencing Batch Reactor.

SRT	Solids retention time - the time taken for solids to pass through a treatment process.
SS	Suspended solids concentration.
TDS	Total Dissolved Solids concentration.
TF	Trickling Filter - a form of biological wastewater treatment.
TKN	Total Kjeldahl Nitrogen concentration - a test to determine the quantity of organic nitrogen and ammonia present in wastewater.
TN	Total Nitrogen concentration - the sum of organic nitrogen, ammonia, nitrite and nitrate.
TP	Total Phosphorus concentration - the sum of organic and inorganic phosphorus.
TSS	Total Suspended Solids concentration.
UV	Ultra Violet irradiation - process used for disinfection.

EXECUTIVE SUMMARY

1 INTRODUCTION

The meat processing industry utilises water on a large scale - current consumption is in the order of 1,500 to 3,000 litre per beast which presents a major undertaking in terms of wastewater management. Environmental policy is undergoing change across the states and territories and this will ultimately impinge on effluent management practices, of which disinfection is only one aspect.

The meat processing industry is itself facing change with the consolidation of operations at centralised plants and the closure of many smaller regional abattoirs. Today there are in the order of 200 abattoirs operating on average 5 hours per day, 5 days a week. By the year 2004, it is expected that further consolidation will have reduced the number of facilities to perhaps 100, operating 5 to 6 days a week in 2 shifts and cleaning. Thus water usage and hence wastewater management requirements will be intensified at those surviving locations.

This report reviews the current effluent standards in place across Australia in relation to evolving environmental policy and considers the possible implications on effluent management practice in the meat processing industry. This is followed by an examination of the technical and economic aspects of the mainstream disinfection processes in the context of meat processing wastewater.

2 MICROBIAL PRESENCE IN WASTEWATER

Microbes present in wastewater effluent include bacteria, fungi, protozoa, viruses and helminths. A large number of these microbes (pathogens) are capable of originating water-borne disease and control by means of disinfection is essential. Standards for microbial quality are generally expressed in terms of the number of Faecal Coliforms present in a 100 mL sample. Typically, the count for raw wastewater will be in the range of 10^7 to 10^8. An environmental authority (license) for the discharge of effluent to a waterway may for example require a count of between 100 and 200 per 100 mL. In this instance the disinfection process would need to achieve a reduction in the range of 10^5 to 10^6.

3 ISSUES THAT CONFRONT THE MEAT PROCESSING INDUSTRY

Issues that confront the meat processing industry relate mainly to evolving environmental policy. The possibility that disinfection will become a requirement and that effluent microbial standards will be increased at some point in the future are issues that need to be considered as these will have significant cost implications.

Disinfection has rarely been a requirement for effluent discharged from meat processing plants. In contrast, regulatory authorities have generally required effluent from municipal sewage treatment plants to be disinfected (mainly by chlorination) prior to release to natural waters or to land. This situation is expected to change with the future and there is the possibility that disinfection will become a requirement for all wastewater generators.

Licenses in the future, in addition to specifying the quantity and quality of effluent discharges, are likely to specify the type of treatment process required as well as pollution abatement measures and investigations funded by the applicant to assess the impact of proposed or existing effluent discharges. Other conditions such as requirements to monitor, to provide certification of compliance with a licence, to undertake and comply with a mandatory environmental audit program and pollution studies, reduction programs and financial assurances are also possible.

Effluent discharges to natural waters are expected to decline with a switch to re-use strategies or land disposal. The effect this will have on disinfection requirements will depend on the form of re-use adopted. In the case of land disposal, the determining factors will include the degree of human/animal contact and crop usage. In the context of the meat processing industry, options for re-use could be very limited. The use of recycled effluent on the meat processing line is not likely to be sanctioned due to the risk of contamination, as well as health & safety issues relating to workers.

The protection of water supply catchments is an issue that could have some impact on the meat processing industry. In the wake of the recent contamination of the Sydney water supply with *Cryptosporidium,* stricter controls are likely to be implemented in the future and these could include restriction of intense animal activities in water supply catchments and upgrading of wastewater treatment processes - which would include disinfection standards.

The use of chemical disinfectants is an issue of particular concern due to the high levels of organic matter and nitrogenous compounds present in meat processing wastewaters. Chemical disinfectants such as chlorine and ozone will react with organic and nitrogenous compounds present in the effluent. Additional disinfectant, over and above that consumed in such reactions, is necessary to achieve the "free" concentration required for disinfection. The consumption of disinfectant, also referred to as a "demand", is normally insignificant with **domestic** effluents. The demand exerted by meat processing effluents, however, can be expected to be much higher and this will have implications in terms of operating costs.

A further consideration is the formation of toxic by-products. The reaction between chlorine and organic and nitrogenous compounds can result in the formation of toxic by-products such as *trihalomethanes* (THMs) which are a major concern in the water industry. Disinfection with ozone also produces by-products but little is known in relation to their toxicity. The high levels of organic and nitrogenous compounds present in meat processing effluent will result in increased levels of by-products which may well exceed acceptable limits. If this is the case, it may transpire that chlorine, and possibly ozone are unacceptable for the disinfection of meat processing wastewaters.

There is the prospect that membrane filtration and ultra violet irradiation will become the mainstream disinfection processes, with added cost implications - both capital and operational. With these processes, however, the high quantity of fat and grease normally present in meat processing wastewaters is an issue that will need to be resolved. Unless adequate pre-treatment is provided these processes will fail.

4 AUSTRALIAN STANDARDS RELATING TO EFFLUENT QUALITY

Since the early 1990s the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Australian Water Resources Council (AWRC) have been engaged in the development of the National Water Quality Management Strategy with the objective of achieving sustainable use of the nations water resources. As part of this process, the Australian Water Quality Guidelines for Fresh and Marine Waters was published in 1992. While this document presents guidelines, as opposed to prescribed standards, and is focused on natural waters, and not wastewaters, it serves as the major reference in the formulation of State environmental policy and in the setting of effluent quality parameters for environmental authorities (licenses). These guidelines are currently under revision with a draft for public comment expected towards the end of 1999. Reports suggest that there will be a change of focus away from specified limits to a philosophy of risk assessment on a site-specific basis.

Environmental Legislation in the individual States and Territories has undergone a major overhaul in recent years. Prior to 1990 most licenses were based on prescribed limits for various parameters such as BOD and SS. There has been a move away from prescribed limits with licenses now being assessed on a case by case basis. License limits are determined through consideration of the range of possible effects including the impact on the environment, human activities, the quantity and quality of effluent, etc. In the case of effluent from meat processing wastewaters it is expected that the risk of spread of infection to humans as well as animals will be a major consideration.

In New South Wales, Load Based Licensing (LBL) has been introduced with emission load limits specified in licences and license fees linked to the emission load. Conditions are also being attached to licenses, examples of which include requirements to monitor, to provide certification of compliance with a licence, to undertake and comply with a mandatory environmental audit program and pollution studies, reduction programs and financial assurances.

There is also a move across the States and Territories to reduce effluent discharges to natural waters and to encourage re-use or, if not feasible, alternative forms of disposal. The discharge of effluent to surface waters is likely to be permitted only if all other options prove unviable. The general move to reduce effluent discharges to natural waters and to promote re-use means that in the future disinfection requirements are likely to be determined by the form of re-use adopted.

5 EFFLUENT DISPOSAL PRACTICE AND ITS INFLUENCE ON DISINFECTION REQUIREMENTS

Disinfection requirements will vary according to the ultimate destination of the effluent which, in the future, is likely to be confined to either discharge to sewer, discharge to land, or some form of reuse.

The discharge of meat processing wastewater to sewer is relatively common in most states with the exception of Queensland. Treatment prior to discharge is usually a combination of extensive primary treatment and shared/part biological treatment.

Discharge to natural waters has in the past been subject to licensing by an environmental regulating authority. Domestic wastewater treatment has typically been in the form of an activated sludge or aerated lagoon process, producing an effluent of reasonable quality which is chlorinated prior to discharge. In contrast, chlorination has generally not been a requirement for the discharge of meat processing effluent. In the future, environmental policy is expected to encourage effluent re-use in one form or another. Effluent discharge to natural waters is likely to be permitted only if all other options have been exhausted. In such instances, license standards are expected to be high, requiring an advanced form of treatment process. The high costs associated with treatment are likely to be a strong incentive to implement a re-use strategy.

Opportunities for effluent re-use in the meat processing industry appear to be limited. The use of disinfected effluent on the process line is not considered an option due to the risk of contamination to processed meat and issues relating to workers health and safety. The only scope for effluent disposal would appear to be confined to irrigation or some form of land disposal. Regulations may require a buffer zone between the disposal area and the processing plant to guard against the risk of aerosol infection.

Wastewater from meat processing plants located in rural areas has mostly been treated in lagoons or discharged to land as these have been the most economical forms of treatment. In the past, statutory control over the microbial quality of effluent discharged to land appears to have been minimal. This situation has now changed and a number of states have published guidelines for effluent irrigation.

6 STANDARD OF WASTEWATER TREATMENT AND ITS INFLUENCE ON DISINFECTION REQUIREMENTS

The standard of wastewater treatment provided can range from the minimal to the sophisticated. In the industry "primary", "secondary" and "tertiary" have become common-place terms to designate the standard of treatment provided. A degree of disinfection is achieved in all forms of treatment, improving with the standard of treatment as would be expected.

Primary treatment includes screening and sedimentation to remove solids present in the wastewater. Smaller solids and soluble constituents pass through the process unaffected. Reduction in microbial numbers is minimal.

Secondary treatment follows the primary stage and involves a form of biological treatment, usually a biofilm process such as trickling filters or an activated sludge process. Secondary effluent is of reasonable quality and the reduction in microbial numbers is greatly improved. Disinfection of secondary effluents can reduce the microbial count to acceptable levels. Biological Nutrient Removal (BNR) processes are an advanced form of secondary treatment and can affect a higher microbial removal, but not significantly.

Tertiary treatment involves a final "polishing" stage such as sand filtration or microfiltration and produces a high quality effluent with low microbial counts.

It is worth noting that the characteristics of wastewaters from the meat processing industry can differ significantly from those of municipal wastewaters. In particular, wastewaters with a high fat and grease content, or a high suspended solids load, which is not substantially removed in the treatment process will impose additional demands on the disinfection system.

7 DISINFECTION TECHNOLOGIES

The range of disinfection technologies available is wide and includes chemical agents such as chlorine, physical processes such as membrane filtration and irradiation processes such as ultra violet light.

Chlorination has been the traditional method of disinfection employed in both water and wastewater treatment. The most common forms of chlorine used are gaseous chlorine, and sodium hypochlorite. Chlorine is a potent oxidising agent and will react with any organic and nitrogenous compounds that may be present in the effluent. This presents two issues that need to be considered:

- a quantity of chlorine will be consumed in the reaction with these compounds and additional chlorine will have to be added to achieve the "free" concentration required for disinfection. The high levels of organic and nitrogenous compounds present in meat processing effluent will increase the consumption of chlorine substantially. This consumption, also referred to as a "demand", will therefore result in a significant increase in operating costs.

- the reaction between chlorine and organic and nitrogenous compounds can result in the formation of toxic by-products which include *trihalomethanes* (THMs) which are a major concern in the water industry. The high levels of organic and nitrogenous compounds present in meat processing effluent will result in increased levels of these by-products which may well exceed acceptable limits. If this is the case, chlorination may not be an acceptable form of disinfection for meat processing effluents. This is an issue that requires further study.

Concern over the effects of chlorine on aquatic life and the possible discharge of toxic by-products to the environment has led to a review of policy in some states on the use of chlorine as a disinfectant.

Ozone has to be generated on site from dry air or oxygen. It is highly reactive, a stronger oxidising agent than chlorine, and considered one of the most effective chemical disinfectants available. Ozone has been used in Europe and the USA as a disinfectant since the 1970's. The early equipment suffered from operational problems but these have been largely overcome with experience, research and development. Ozone has not had extensive use in Australia and at present there are very few installations.

Destruction of bacteria and viruses is rapid compared with chlorine which requires a long contact period. Ozone does not provide a residual concentration due to its high reactivity and low solubility. It rapidly decomposes to oxygen which is advantageous in maintaining a dissolved oxygen level in the purified effluent. Ozone generating equipment would normally be housed within a building and, because of corrosion problems, all metal work and piping needs to be fabricated from stainless steel. Compared to chlorination systems, the capital cost of ozone generating equipment is high. Until recently, ozone generators were only manufactured overseas and with added importation costs, this has not been an economic option. More recently, however, Australian companies have begun to manufacture ozone generators. This has reduced the capital cost of equipment to some extent but the overall cost remains high.

Ozone, like chlorine, will react with any organic and nitrogenous compounds that may be present in the effluent. The formation of toxic by-products is reported to be less with ozone however, further research is needed to confirm this. The possibility needs to be considered that the levels of toxic by-product formed may exceed acceptable limits. If this is the case, ozone may not be an acceptable form of disinfection for meat processing effluents.

Continuous Membrane Filtration (CMF) is an emerging technology available in a variety of forms including reverse osmosis, ultrafiltration, nanofiltration and microfiltration. These technologies provide a physical means of disinfection with excellent removals. From a disinfection perspective, ultrafiltration is considered the most appropriate form of membrane process. Alternatives such as reverse osmosis and nanofiltration operate under much higher pressures and have correspondingly higher capital and operating costs. Membrane processes require a high quality feed water and adequate pretreatment is essential. It should be emphasised that unless adequate upstream treatment is provided, a membrane process will fail. Both capital and operating costs are high.

UV disinfection is seeing increasing use at municipal sewage treatment plants as an alternative to chlorination. UV disinfection does not provide a residual and, from an environmental perspective, there is the view that this creates less harm in the discharge of effluent to aquatic environments. However, it requires a very effective 'kill' as disinfection ceases on exiting the UV system. Successful operation requires an effluent with high light transmissivity i.e. low suspended solids, colour and turbidity. A large quantity of research data has been published from numerous laboratory studies and pilot plant trials that have been carried out. However, the success often reported has not always been replicated in full scale installations. Problems that have emerged at plant scale include higher than expected power demands and difficulty in meeting the licence requirements. Many of these problems can be attributed to effluents with a low transmissivity or the formation of scale on the lamps. In respect to meat processing wastewaters, this is likely to be a major problem. Operating costs are high and include power, lamp replacement, cleaning and maintenance.

Electrochemical disinfection is a recent technology that has been used in Australia for the disinfection of domestic swimming pool water and in small-scale potable water purification. It is now being marketed under the trade name *Positron* as a technology for disinfection of effluent from on-site domestic wastewater package plants. Electrochemical disinfection is reported to be capable of destroying a wide variety of microorganisms, including viruses, bacteria, algae as well as larger species. There are also reports that the technology can remove ionic impurities such as sulphates, phosphates, chlorides, heavy metals and organic compounds. The process is also reported to reduce turbidity and improve the taste and odour of water. The *Positron* process operates off a standard 220 volt AC supply which is transformed to a DC current of less than one amp. The electrode assembly is mounted in a pipe and, depending on the flow rate, several units may be installed in series. It has been found that performance is improved if the disinfected effluent is retained for a period of two to six hours.

This technology could offer positive advantages over established disinfection processes. Operating costs are a fraction of those for chlorination, ozone and ultra violet irradiation processes. The complex mixture of disinfecting agents generated has the potential to reach a wider range of micro-organism species and effect a greater removal of pathogens. The capability to remove turbidity and other impurities suggests that a high quality final effluent could be achieved at low expense. The potential benefits to the meat processing industry warrant further investigation.

8 CONCLUSIONS

Issues that confront the meat processing industry relate mainly to evolving environmental policy. Indications are that the future will see a reduction in effluent discharge to natural waters and a shift to land disposal and re-use schemes. As far as the meat processing industry is concerned, effluent re-use appears to be limited to "external" activities. The use of reclaimed wastewater on the production line is not considered viable due to the risk of contamination and workplace health & safety issues.

All of the mainstream disinfection technologies - chlorination, ozonation, UV irradiation and membrane filtration are capable of achieving the effluent standards. UV irradiation and membrane filtration, however, will only operate on very high quality effluent. Ozone, UV and membrane filtration have high capital and operating costs. Chlorination is the most economic disinfection process, but may not be an acceptable form of disinfection for meat processing effluents because of toxic by-product formation.

Electrolytic disinfection is an untrialed technology in respect to meat processing wastewaters and could offer improved disinfection at lower operating costs.

1 INTRODUCTION

The meat processing industry utilises water on a large scale - current consumption is in the order of 1,500 to 3,000 litre per beast (MLA, 1998) which presents a major undertaking in terms of wastewater management. Environmental policy is undergoing change across the states and territories and this will ultimately impinge on effluent management practices, of which disinfection is only one aspect.

The meat processing industry is itself facing change with the consolidation of operations at centralised plants and the closure of many smaller regional abattoirs. Today there are in the order of 200 abattoirs operating on average 5 hours per day, 5 days a week. By the year 2004, it is expected that further consolidation will have reduced the number of facilities to perhaps 100, operating 5 to 6 days a week in 2 shifts and cleaning (Johns, 1999). Thus water usage and hence wastewater management requirements will be intensified at those surviving locations.

This report reviews the current effluent standards in place across Australia in relation to evolving environmental policy and considers the possible implications on effluent management practice in the meat processing industry. This is followed by an examination of the technical and economic aspects of the mainstream disinfection processes in the context of meat processing wastewater.

The broad objective of this report is to provide information that can assist meat processors to achieve sustainable effluent management and to help maintain the viability and environmental sustainability of the red meat industry in Australia.

2 MICROBIAL PRESENCE IN WASTEWATER

Microbes present in wastewater include bacteria, fungi, protozoa, viruses and helminths. A large number of these microbes (pathogens) are capable of originating water-borne disease and control by means of disinfection is essential. Some of the pathogenic microbes commonly found in **domestic** wastewater are shown in Table 2. Different strains and numbers may be present in meat processing wastewaters. For example - Q fever is not considered a risk in the context of domestic wastewater. However, in the meat processing industry, it is a major issue.

Monitoring of effluent for the wide range of known pathogens is not practical and methods of detecting pathogens are time consuming, complex and expensive. In practice, organisms that can be easily identified and counted are used as indicators to monitor for pathogenic contamination. Indicator organisms used include Total Coliforms, Faecal Coliforms and *Escherichia. coli* (*E.coli*). Coliform bacteria are used as an indicator in the monitoring of drinking water quality. Bacteria in this group can originate from vegetation and soil and are not specific indicators of faecal pollution. The Faecal Coliform group is a more reliable indicator of faecal pollution, particularly the strain *E. coli* which is specifically of faecal origin. The Faecal Streptococci group has been proposed as an indicator of the source of faecal pollution. It has been found that the ratio of Faecal Coliforms to Faecal Streptococci in human waste is significantly different to that for animal wastes.

Standards for microbial quality are generally expressed in terms of the number of Faecal Coliforms present in a 100 mL sample. Typically, the count[1] for raw wastewater will be in the range of 10^7 to 10^8. An environmental authority (license) for the discharge of effluent to a waterway may for example require a count of between 100 and 200 per 100 mL. In this instance the disinfection process would need to achieve a reduction in the range of 10^5 to 10^6.

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[1]It has become customary to express large numbers such as these in exponential form - for example 10,000,000 is more conveniently expressed as 10^7. In the water industry, the microbial count is frequently referred to in logarithmic terms - for example 10^7 would be referred to as "log 7" and a reduction from 10^7 (ie. log 7) to 10^2 (ie. log 2) would be referred to as a "5 log reduction". The log reduction is simply the difference of the two logs, ie. 7 - 2 = 5.

Table 2. Pathogenic micro-organisms found in raw domestic wastewater

Organism	Disease	Remarks
Bacteria		
Escherichia coli (enteropathogenic)	Gastroenteritis	Diarrhea
Legionella pneumophila	Legionellosis	Acute respiratory illness
Leptospira	Leptospirosis	Jaundice, fever (Weil's disease)
Salmonella typhi	Typhoid fever	High fever, diarrhea, ulceration of small intestine
Salmonella	Salmonellosis	Food poisoning
Shigella	Shigellosis	Bacillary dysentery
Vibrio cholerae	Cholera	Extremely heavy diarrhea, dehydration.
Yersinia enterolitica	Yersinosis	Diarrhea
Viruses		
Adenovirus (31 types)	Respiratory disease	
Enteroviruses (67 types, e.g., polio, echo and Coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis	
Hepatitis A	Infectious hepatitis	Jaundice, fever
Norwalk agent	Gastroenteritis	Vomiting
Reovirus	Gastroenteritis	
Rotavirus	Gastroenteritis	
Protozoa		
Balantidium coli	Balantidiasis	Diarrhea, dysentery
Cryptosporidium	Cryptosporidiosis	Diarrhea
Entamoeba histolytica	Amebiasis (amoebic dysentery)	Prolonged diarrhea with bleeding, abscesses of the liver and small intestine
Giardia lamblia	Giardiasis	Mild to severe diarrhea, nausea, indigestion
Heiminths		
Ascaris lumbricoides	Ascariasis	Roundworm infestation
Enterobius vericularis	Enterobiasis	Pinworm
Fasciola hepatica	Fascioliasis	Sheep liver fluke
Hymenolepis nana	Hymenolepiasis	Dwarf tapeworm
Taenia saginata	Taeniasis	Beef tapeworm
T. solium	Taeniasis	Pork tapeworm
Trichuris trichiura	Trichuriasis	Whipworm

Source: Metcalf & Eddy (1991)

3 ISSUES THAT CONFRONT THE MEAT PROCESSING INDUSTRY

3.1 Introduction

Issues that confront the meat processing industry relate mainly to evolving environmental policy. The possibility that disinfection will become a requirement and that effluent microbial standards will be increased at some point in the future are issues that need to be considered as these will have significant cost implications.

3.2 Requirement to Disinfect Effluent

Disinfection has rarely been a requirement for effluent discharged from meat processing plants. In contrast, regulatory authorities have generally required effluent from municipal sewage treatment plants to be disinfected (mainly by chlorination) prior to release to natural waters or to land. This situation is expected to change with the future and there is the possibility that disinfection will become a requirement for all wastewater generators.

3.3 Mainstream environmental policy

Licenses in the future, in addition to specifying the quantity and quality of effluent discharges, are likely to specify the type of treatment process required as well as pollution abatement measures and investigations funded by the applicant to assess the impact of proposed or existing effluent discharges. Other conditions such as requirements to monitor, to provide certification of compliance with a licence, to undertake and comply with a mandatory environmental audit program and pollution studies, reduction programs and financial assurances are also possible.

Effluent discharges to natural waters are expected to decline with a switch to re-use strategies or land disposal. The effect this will have on disinfection requirements will depend on the form of re-use adopted. In the case of land disposal, the determining factors will include the degree of human/animal contact and crop usage.

In the context of the meat processing industry, options for re-use could be very limited. The use of recycled effluent on the meat processing line is not likely to be sanctioned due to the risk of contamination, as well as health & safety issues relating to workers.

Where discharges to natural waters are permitted, it is probable that chlorination will ultimately be phased out due to concerns for the effect on aquatic life. There is the prospect that membrane filtration and ultra violet irradiation will become the mainstream disinfection processes, with added cost implications - both capital and operational.

3.4 Protection of water supply catchments

The presence of *Cryptosporidium*and *Giardia* in potable water supplies has become a major issue in the water industry, worldwide. Both organisms are parasitic protozoan which, for part of their life cycle, inhabit the intestines of animals. At a at particular stage the organism develops a resistant outer coating and is transformed into a cyst. Cysts are transmitted by water and if ingested can lead to infection in humans.

The Australian Drinking Water Guidelines (ARMCANZ, 1996) advocate a wide-ranging program of protection, treatment and monitoring to ensure the microbiological safety of water supplies, with barriers to the entry and transmission of pathogens throughout the system. Such barriers include the protection of water supply catchments from human and animal faecal contamination.

The intense media and political reaction to the contamination of the Sydney water supply with *Cryptosporidium* over the period from July to September 1998 suggests that stricter controls may be implemented in the future. These could include restriction of intense animal activities in water supply catchments and upgrading of wastewater treatment processes - which would include disinfection standards.

3.5 Effluent Quality

The technology developed for the treatment of domestic wastewater has evolved to a point where it is capable of producing an effluent of acceptable quality. The same technology applied to meat processing wastewater, however, will have difficulty in achieving a similar effluent standard. This is due to the higher pollutant load which is evident in the comparison with domestic wastewater shown in Table 3.5. Meat processing effluents are more likely to have much higher levels of organic matter, nitrogenous compounds and phosphates than domestic wastewater effluents.

Table 3.5. Comparison of meat processing and domestic wastewaters

Characteristic (raw wastewater)	**Typical range (mg/L)**	
	Meat processing	**Domestic sewage**
COD†	2,000 - 6,000	350 - 1,000
Total-N	100 - 250	30 - 80
Total-P	20 - 50	6 - 30

† Chemical oxygen demand - a parameter that reflects the amount of organic matter present in the wastewater.

Chemical disinfectants such as chlorine will react with any organic and nitrogenous compounds that may be present in the effluent. Chlorine will be consumed in the reaction and more chlorine will need to be added to achieve the "free" concentration required for disinfection. The consumption of disinfectant, also referred to as a "demand", will vary according to the quantity of organic matter and nitrogenous compounds present in the effluent. With **domestic** effluents, the demand is normally insignificant. The demand exerted by meat processing effluents, however, can be expected to be much higher and this will have implications in terms of operating costs. This will be an issue that the meat processing industry will need to address and effluent quality is likely to have a major bearing on both the form of disinfection process adopted and its performance.

3.6 Toxic by-product formation

The reaction between chlorine and organic and nitrogenous compounds can result in the formation of toxic by-products such as *trihalomethanes* (THMs) which are a major concern in the water industry. Disinfection with ozone also produces by-products but little is known in relation to their toxicity. The high levels of organic and nitrogenous compounds present in meat processing effluent will result in increased levels of by-products which may well exceed acceptable limits. If this is the case, it may transpire that chlorine, and possibly ozone are unacceptable for the disinfection of meat processing wastewaters.

There is the prospect that membrane filtration and ultra violet irradiation will become the mainstream disinfection processes, with added cost implications - both capital and operational. With these processes, however, the high quantity of fat and grease normally present in meat processing wastewaters is an issue that will need to be resolved. Unless adequate pre-treatment is provided these processes will fail.

4 AUSTRALIAN STANDARDS RELATING TO EFFLUENT QUALITY

4.1 Introduction

Under the Australian Constitution management and protection of the environment is the responsibility of the States and Territories. The role of the Commonwealth has been to provide a national forum for co-operation and consultation between States, Territories and the Commonwealth and in the development of policies for the long-term management of water resources.

4.2 Review of National Standards

In the early 1990s the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Australian Water Resources Council (AWRC) embarked on the development of the National Water Quality Management Strategy with the objective of achieving sustainable use of the nations water resources. Philosophies and policies are set out in the Discussion Paper "Water Quality - Towards a National Policy" (ANZECC, 1992). In 1992 a series of draft guidelines were published and those that are relevant to this report include:

4.2.1 Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC, 1992)

While this document presents guidelines, as opposed to prescribed standards, and is focused on natural waters, and not wastewaters, it serves as the major reference in the formulation of State environmental policy and in the setting of effluent quality parameters for environmental authorities (licenses). These guidelines are currently under revision with a draft for public comment expected towards the end of 1999. It has been reported (Hart *et al*, 1998 and Swinton, 1999) that there will be a change of focus away from specified limits to a philosophy of risk assessment on a site-specific basis.

4.2.2 Draft Guidelines for Sewerage Systems: Effluent Management (AWRC, 1992)

This document provides guidelines on effluent parameters for the discharge of municipal wastewater effluent to land, inland waters and marine waters. Criteria are very broad based and those relating to disinfection are summarised in Table 4.2.2 below.

Table 4.2.2. Summary of Disinfection Criteria from Draft Guidelines

Disposal Route	**Guideline treatment level**[1]	**Higher treatment level**[2] **(site specific)**
Land application	(none)	• irrigation • agriculture • landscape • wetlands • infiltration
Discharge to inland waters	recreation - primary contact	• agricultural water supply • maintenance of aquatic ecosystems • recreation - secondary contact • recreation - primary contact
Discharge to marine waters	(none)	• ocean - near shore or populated • open bays and estuaries • maintenance of aquatic ecosystems • recreation - primary contact

Notes:

1. Guideline treatment level is the minimum level of treatment required. The guidelines acknowledge that in some instances lower levels of treatment may be acceptable.
2. The guidelines note that in some circumstances a higher level of treatment will be required.
3. The guidelines list appropriate disinfection processes as "lagooning, UV irradiation and chlorination.

4.2.3 Draft Guidelines for Sewerage Systems: Acceptance of Trade Wastes (AWRC, 1992)

These guidelines were developed to support a national approach to trade waste management and the document recommends adoption by authorities as the basis for acceptance of waste discharged to sewer. The document lists acceptance criteria for a range of parameters. Reference to disinfection is contained only in the parameter named **Infectious Wastes** for which the criteria (in part) is stated as:

> "Medical, clinical, veterinary and other pathological wastes may be prohibited or required to be rendered non-infectious prior to discharge if they are deemed to be a threat to health and safety operations and maintenance personnel or the community."

It is the view of the authors that this criteria is meant to apply to pathological wastes from hospitals, laboratories, etc and not to meat processing wastewater.

4.3 Review of State and Territory Standards

Environmental Legislation in the individual States and Territories has undergone a major overhaul in recent years. Prior to 1990 most licenses were based on prescribed limits for various parameters such as BOD and SS. There has been a move away from prescribed limits with licenses now being assessed on a case by case basis.

License limits are determined through consideration of the range of possible effects including the impact on the environment, human activities, the quantity and quality of effluent, etc. In the case of effluent from meat processing wastewaters it is expected that the risk of spread of infection to humans as well as animals will be a major consideration.

In New South Wales, Load Based Licensing (LBL) has been introduced with emission load limits specified in licences and license fees linked to the emission load. Conditions are also being attached to licenses, examples of which include requirements to monitor, to provide certification of compliance with a licence, to undertake and comply with a mandatory environmental audit program and pollution studies, reduction programs and financial assurances.

There is also a move across the States and Territories to reduce effluent discharges to natural waters and to encourage re-use or, if not feasible, alternative forms of disposal. The discharge of effluent to surface waters is likely to be permitted only if all other options prove unviable.

It is constructive at this point to briefly review developments in environmental regulation in the states and territories.

4.4 New South Wales

The regulatory authority in new South Wales is the Environment Protection Authority (NSW EPA), established in March 1992 under the Protection of the Environment Administration Act 1991. Recent developments include:

- the consolidation of key pollution statutes under a single Act - the Protection of the Environment Operations Act 1997 (POEO Act)
- the introduction of load-based licensing (LBL) on 1 July 1999 under the Protection of the Environment Operations (General) Regulation 1998
- additional regulations relating to waste management are in preparation and were also due for publication on 1 July 1999.

4.5 Victoria

In Victoria the regulatory authority is the Environmental Protection Authority (VIC EPA) which administers the Environment Protection Act 1970. Recent developments include:

- the introduction of Works Approvals for prescribed industries under the Environment Protection (Scheduled Premises And Exemptions) Regulations 1995

Effluent discharges are controlled by the EPA through a works approval and licensing system. The licence for each input specifies the quality and quantity of the waste permitted to be discharged. State Environment Protection Policy (SEPP) requires that these licences be drawn up in such a way that water quality objectives for the receiving waters are met.

4.6 South Australia

In South Australia, environmental protection is the responsibility of the Environmental Protection Authority (SA EPA). The principal environmental legislation is the Environment Protection Act 1993. Other legislation is currently under development.

4.7 Western Australia

Environmental protection is the responsibility of the Environmental Protection Authority (WA EPA). Recent developments include:

- the formation of the Department of Environmental Protection 1994 as a result of changes to the Environmental Protection Act 1986

4.8 Queensland

In Queensland the regulatory authority is the Environmental Protection Agency (EPA) formed in 1998 by the renaming of the Department of Environment and Heritage. The principal legislation is the Environmental Protection Act 1994. Recent developments include:

- The designation of environmentally relevant activities under the Environmental Protection Regulation 1998, replacing the Environmental Protection (Interim) Regulation. Wastewater treatment is designated as an Environmentally Relevant Activity and requires an Environmental Authority (license)

- passage of the Environmental Protection (Water) Policy 1997 which:

    - details management of activities including releases to land, water and groundwaters, artificial wetlands, biological controls, and monitoring.

    - provides for the development and implementation of environmental plans for water including plans for managing sewage, trade waste, water conservation and for protection of surface and groundwaters.

4.9 Tasmania

The Department of Environment and Planning is responsible for environmental protection. The Environmental Management and Pollution Control Act 1994 (EMPCA) is the primary environment protection legislation in Tasmania, developed in the early 1990s. Some parts of the EMPCA commenced in 1995, but the bulk of the Act did not commence until January 1996. Subordinate legislation includes:

- the Environment Protection (Waste Disposal) Regulations 1974 from the previous Environment Protection Act and carried over to EMPCA pending the development of new Regulations or a waste management policy. The Regulations will be automatically rescinded on 1 January 2000.

- The Environment Protection (Water Pollution) Regulations, 1974, set emission limit standards for discharges from point sources (industries, sewage treatment plants etc.) to waterways. The Regulations will be automatically rescinded on 1 January 2000.

Recent developments include:

- passage of the State Policy on Water Quality Management in June 1997 requiring point sources of pollution to be managed by the setting of emission limits in permits. Limits are to be set on a case by case basis in accordance with key principles including the reduction of waste emissions as far as reasonable and practical. The Policy provides for the publishing of "emission limit guidelines" for common activities which are likely emit relatively small pollutant loads. The Policy prohibits discharges to groundwater other than in special circumstances. This Policy has been designed specifically to replace the Water Pollution Regulations. The Regulations and the Policy will exist concurrently (until the Regulations are automatically rescinded on 1 January 2000) while the requirements of the Policy are phased in.

4.10 Northern Territory

In the Northern territory the regulatory authority is the Department of Lands, Planning and Environment which is responsible for environmental policies, waste management and pollution control and which administers the Waste Management and Pollution Control Act. Recent developments include:

- implementation of the Waste Management and Pollution Control Act on 1 February 1999. Sections of the Act dealing with environmental licences and approvals will commence at a later date.

4.11 Australian Capital Territory

In the Australian Capital Territory (ACT) the regulating authority is the Environment Management Authority, part of Environment ACT. The principal environmental legislation is the Environmental Protection Act. Recent developments include:

- the passage of the Environmental Protection Act 1997, which took effect on 1 June 1998.

4.12 Summary

There has been a collective restructuring of environmental regulatory authorities in parallel with a revision of environmental protection legislation across the States and Territories. The major impact of these changes in relation to effluent disinfection is that in most cases, prescribed limits are being replaced by site-specific standards determined by the regulatory authority. As far as can be determined, there appear to be no prescribed standards for microbial concentrations in wastewater effluent. A further impact is on the means of effluent disposal, which has an indirect bearing on disinfection requirements. The general move to reduce effluent discharges to natural waters and to promote re-use means that in the future disinfection requirements are likely to be determined by the form of re-use adopted.

The principal environmental legislation in the states and territories is summarised below:

State/Territory	**Legislation**
New South Wales	Protection of the Environment Administration Act 1991 Protection of the Environment Operations Act 1997
Victoria	Environment Protection Act 1970
Queensland	Environmental Protection Act 1994
Wester Australia	Environmental Protection Act 1986
South Australia	Environment Protection Act 1993
Tasmania	Environmental Management and Pollution Control Act 1994
Australian Capital Territory	Environment Protection Act 1997
Northern Territory	Waste Management and Pollution Control Act 1998

5 EFFLUENT DISPOSAL PRACTICE AND ITS INFLUENCE ON DISINFECTION REQUIREMENTS

5.1 Introduction

It is constructive at this point to briefly review effluent disposal practices in Australia as this provides a context/baseline to view future practice and the bearing this is likely to have on disinfection requirements.

The discharge of wastewater effluent to inland waters is confined to the smaller communities and places such as Canberra and several of the large cities and towns in Queensland. In most instances secondary treatment is a minimum requirement, followed by effluent disinfection. Many of the larger treatment plants have now been upgraded to provide nutrient removal.

The discharge of effluent from municipal treatment plants to marine waters is common, particularly in the developed coastal communities and occurs either directly through a marine outfall or indirectly through discharge to estuaries. The level of treatment provided varies from minimal to secondary treatment and at some treatment plants, nutrient removal has now been added.

The discharge of effluent to land has been influenced by the availability of land, climate, topography and soil conditions. Land disposal systems include evaporation ponds, irrigation, soakage ponds and artificial wetlands. With the latter two systems, effluent ultimately reaches the ground water or nearby surface waters.

Disinfection requirements will vary according to the ultimate destination of the effluent which, in the future, is likely to be confined to either discharge to sewer, discharge to land, or some form of reuse.

5.2 Discharge to sewer

The discharge of meat processing wastewater to sewer is relatively common in most states with the exception of Queensland. Treatment prior to discharge is usually a combination of extensive primary treatment and shared/part biological treatment.

5.3 Discharge to natural waters

Discharge to natural waters has in the past been subject to licensing by an environmental regulating authority. Domestic wastewater treatment has typically been in the form of an activated sludge or aerated lagoon process, producing an effluent of reasonable quality which is chlorinated prior to discharge. In contrast, chlorination has generally not been a requirement for the discharge of meat processing effluent.

Current environmental policy encourages effluent re-use in one form or another. In the future, effluent discharge to natural waters is likely to be permitted only if all other options have been exhausted. In such instances, license standards are expected to be strict, requiring an advanced form of treatment process. The high costs associated with treatment are likely to be a strong incentive to implement a re-use strategy. Typical microbial limits for natural waters are shown in Table 5.3.

Table 5.3. Typical microbial limits in natural waters

Primary contact ¶ The median bacterial content in samples of fresh or marine waters should not exceed: • 150 faecal coliform organisms/100 mL (minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less than 600 organisms/100 mL); • 35 enterococci organisms/100 mL (maximum number in any one sample: 60-100 organisms/100 mL). Pathogenic free-living protozoans should be absent from bodies of fresh water.
Secondary contact § The median bacterial content in fresh and marine waters should not exceed: • 1,000 faecal coliform organisms/100 mL (minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less than 4,000 organisms/100 mL); • 230 enterococci organisms/100 mL (maximum number in any one sample 450-700 organisms/100 mL).

¶ swimming and direct contact activities
§ boating, fishing, etc
Source: Australian Drinking Water Guidelines

5.4 Effluent re-use opportunities

Opportunities for effluent re-use in the meat processing industry appear to be limited. The use of disinfected effluent on the process line is not considered an option in view of the risk of contamination to processed meat and issues relating to workers health and safety. The only scope for effluent disposal would be confined to irrigation or some form of land disposal. Regulations may require a buffer zone between the disposal area and the processing plant to guard against the risk of aerosol infection (eg. see DNR QLD, 1996).

5.5 Discharge to land

Wastewater from meat processing plants located in rural areas has mostly been treated in lagoons and discharged to land as these have been the most economical forms of treatment. In the past, statutory control over the microbial quality of effluent discharged to land appears to have been minimal. This situation has now changed and a number of states have published guidelines on effluent irrigation (EPA NSW 1995, EPA SA 1996, EPA VIC 1991, DNR QLD 1996). It should be emphasised that these documents are no more than *guidelines* and do not obviate the necessity for works approvals or operating licenses. The various guidelines are briefly reviewed in the following sections.

5.5.1 New South Wales

Draft guidelines were published in 1995 and these are expected to be finalised at some point in 1999. The Guidelines apply to a wide range of rural and industrial effluents, including secondary treated sewage effluent. Wastewater is required to be treated to at least a secondary level and the effluent must be disinfected. The Draft Guidelines note that it has been wide-spread practice in NSW for sewage treatment plants to achieve acceptable disinfection by holding effluent in ponds for a minimum of 10 days. Disinfection requirements are reproduced in Table 5.5.1.

Table 5.5.1. NSW Disinfection Requirements for Irrigated Effluent

Applications	Minimum disinfection level	Provisos
Grass and landscaped areas	B	Public excluded during spraying
Pastures for fodder crops	C	Public excluded during spraying and crops not harvested for 10 days
	B	Public excluded during spraying
Pastures for grazing animals	C	Public excluded during spraying and animals excluded for 10 days
Orchards, vineyards	C	Dropped fruit not to be harvested for consumption
Crops for human consumption which undergo commercial processing	A	Processing system approved by the Department of Health
Crops for human consumption which are cooked before consumption	A	None
Forest areas, mining and quarry rehabilitation areas	C	Public excluded during spraying

Disinfection Levels are defined as follows:

Disinfection Level	Minimum Bacteriological Requirement (faecal coliforms/100mL)		Acceptable Disinfection Technique
A	Geometric mean Upper limit	<300 <2,000	30 days ponding or other means acceptable to the EPA and Dept of Health
B	Geometric mean Upper limit	<750 <5,000	20 days ponding or other means acceptable to the EPA and Dept of Health
C	Geometric mean Upper limit	<3,000 <14,000	10 days ponding or other means acceptable to the EPA and Dept of Health

5.5.2 South Australia

In South Australia restrictions apply under the Stock Act, 1990, to cattle and pigs grazed on pastures irrigated with sewage effluent. Restrictions also apply to the sale or distribution of hay grown on pastures irrigated with sewage effluent.

According to Technical Bulletin No. 13 (EPA SA, 1996) the Chief Veterinary Officer considers sewage effluent from a treatment process with a retention period in excess of 25 days to be exempt from the provisions of the Stock Act and notes that the major concern is the infection of cattle and pigs with tapeworm helminths.

5.5.3 Victoria

Guidelines for Wastewater Irrigation were in published 1983 and revised in 1991. Wastewater is required to be treated to a secondary level. Disinfection requirements for various uses are summarised in Table 5.5.3

Table 5.5.3. VIC Disinfection Requirements for Irrigated Effluent

Use	**Faecal coliform count** (organisms per 100 mL)
Flood, furrow, drip or spray irrigation of • trees • pasture or fodder crops **excluding pigs, beef cattle, dairy cows** • landscaped public recreation areas **subject to Health Department conditions**	30 days retention and: median < 1,000 90 percentile <2,000
Flood, furrow, drip or spray irrigation of • pasture or fodder crops for beef cattle and dairy cows	60 days retention. (No coliform count specified)
Irrigation of crops for human consumption	Must be referred to Health Department Victoria

5.5.4 Queensland

In Queensland interim guidelines (QLD DNR, 1996) have been produced as a first stage to the development of guidelines for the re-use of reclaimed wastewater. The Guidelines note that lagoons are not capable of reducing faecal coliform counts to below 10/100 mL which makes them unsuitable for effluents with a high contact use.

Table 5.5.4. QLD Disinfection Requirements for Irrigated Effluent

Applications	Minimum disinfection level	Provisos
Grass and landscaped areas - **uncontrolled access**	A	• Public excluded during spraying. • Withholding period of 4 hours or until area is dry.
Grass and landscaped areas - **controlled access**	B	• None
Pastures for fodder crops	C	• Public excluded during spraying and crops not harvested for 10 days. • Withholding period of 10 days before harvesting. • Harvested crop must be dry before bailing.
Pastures for sheep, cattle, horses and other grazing animals - **no withholding period**	A	• Beef measles control • Excludes dairy cattle
Pastures for sheep, cattle, horses and other grazing animals - **withholding period**	C	• Public excluded during spraying. • Withholding period of 5 days before grazing. • Excludes dairy cattle.
Pastures for dairy cattle	A	• No withholding period • Beef measles control
Orchards, vineyards - **spray irrigation**	A	• Holding period of 2 weeks before fruit is picked.
Orchards, vineyards - **furrow/drip irrigation**	C	• Dropped fruit not to be harvested for consumption
Food production - **not processed**	A	• None
Edible crops - **not processed and not in direct contact with effluent**	B	• Separation of crop from effluent
Edible crops - **processed**	C	• None
Forest areas, mining and quarry rehabilitation areas	C	• Public excluded during spraying • Withholding period of 4 hours
Industrial - **closed system, no human contact**	C	• Additional treatment to prevent biological growth, fouling and foaming
Industrial - **open system, human contact possible**	C	• Minimise wind-blown spray • Additional treatment to prevent biological growth, fouling and foaming

Disinfection levels are defined as follows:

Disinfection Level	Minimum Bacteriological Requirement (faecal coliforms/100mL)		Acceptable Disinfection Technique
A	Median value[1] 4 out of 5 samples	10 <20	Chlorination, UV, ozone or membrane filtration
B	Median value[1] 4 out of 5 samples	150 <600	Chlorination, UV, ozone or 30 days ponding
C	Median value[1] 4 out of 5 samples	1,000 <4,000	Chlorination, UV or 20 days ponding

Notes:
1. Median value calculated from 5 samples collected at not less than half-hourly intervals.

5.5.5 Comparison

Similarities can be seen between the NSW and QLD guidelines, both of which have adopted an A, B, C form of classification. By comparison, the VIC guidelines and the SA Bulletin are far less comprehensive. The difference is merely a reflection of evolving environmental policy across the states and territories - the NSW and QLD guidelines were published in 1995/96; the VIC document, originally published in 1983, was last revised in 1991. Ultimately, compatible standards will emerge across all states and territories.

It should be noted that most of the guidelines are based on effluent from **domestic** wastewater and are not explicitly aimed at industrial wastewaters. They are, however, equally relevant to meat processing wastewaters. A list of available guidelines is shown in Table 5.5.5.

Table 5.5.5. List of available guidelines on effluent discharge to land

Guideline	Publisher
Draft Environmental Guidelines for Industry: The utilisation of treated effluent by irrigation. Publication EPA 95/20 1995	Environment Protection Authority, New South Wales.
Guidelines for Wastewater Irrigation. Publication 168 1991	Environment Protection Authority, Victoria.
Interim Guidelines for Reuse or Disposal of Reclaimed Wastewater. 1996	Department of Natural Resources, Queensland.
Irrigation with water reclaimed from sewage treatment on pastures used for grazing of cattle and pigs. Technical Bulletin. 1996	Environmental Protection Authority, South Australia.

6 STANDARD OF WASTEWATER TREATMENT AND ITS INFLUENCE ON DISINFECTION REQUIREMENTS

6.1 Introduction

The standard of wastewater treatment provided can range from the minimal to the sophisticated. In the industry "primary", "secondary" and "tertiary" have become common-place terms to designate the standard of treatment provided. A degree of disinfection is achieved in all forms of treatment, improving with the standard of treatment as would be expected.

6.2 Primary treatment

Primary treatment includes screening and sedimentation (or flotation) to remove solids present in the wastewater. Smaller solids and soluble constituents pass through the process unaffected. The reduction in microbial numbers is minimal. In the meat industry, dissolved air flotation (DAF) is a process that has been used widely. As a primary unit, DAF offers two positive advantages in relation to disinfection:

- pre-treatment to remove solids, fat and grease which would otherwise block physical processes such as membrane filtration or impose high demands on chemical processes such as chlorination.

- removal of microbes attached to the solids, reducing the load on the disinfection system.

6.3 Secondary treatment

Secondary treatment follows the primary stage and involves a form of biological treatment, usually a biofilm process such as trickling filters or an activated sludge process. Secondary effluent is of reasonable quality and the reduction in microbial numbers is greatly improved. Disinfection of secondary effluents can reduce the microbial count to acceptable levels. Biological Nutrient Removal (BNR) processes are an advanced form of secondary treatment and can affect a higher microbial removal, but not significantly.

6.4 Tertiary treatment

Tertiary treatment involves a final "polishing" stage such as sand filtration or microfiltration and can produce a high quality effluent with low microbial counts. As a tertiary unit, DAF has the potential to perform a disinfection role in situations where perhaps only a 2 log reduction is required. The process might be enhanced by utilising a polymer to coagulate the suspended solids and microbes present in the effluent.

A comparison of microbial counts in effluent for various standards of treatment is shown in Table 6.4.

Table 6.4. Indicative values of microbial count for effluents from different levels of treatment

Treatment Process	E. Coli count (org/100mL)
Raw wastewater (municipal)	10^7-10^8
Primary treatment • screening • sedimentation	10^6-10^7
Secondary treatment • activated sludge • trickling filters • lagoons	10^5-10^6
Disinfection • lagoons • UV • chlorination	$< 10^3$
Tertiary treatment • sand filtration • microfiltration	$< 10^2$

Source: ARMCANZ (1996) National Water Quality Management Strategy: *Australian Drinking Water Guidelines.*

At the expense of what may appear obvious, it is worth noting that the characteristics of wastewaters from the meat processing industry can differ significantly from those of municipal wastewaters and that this can have an influence on the efficacy of the disinfection process. In particular, wastewaters with a high fat and grease content, or a high suspended solids load, which is not substantially removed in the treatment process will impose additional demands on the disinfection system.

7 DISINFECTION TECHNOLOGIES

7.1 Introduction

There is a wide variety of disinfection technologies available including chemical agents such as chlorine, physical processes such as membrane filtration and irradiation processes such as ultra violet light. A comprehensive overview has been provided in a recent report from MIRINZ (Donnison, 1996). In this section, the review will be limited to the mainstream technologies that have application in the meat processing industry. Other disinfection technologies are listed in Table 7.1. It should be stressed that these technologies are not in frequent use and little if any information is available concerning their effectiveness with meat processing effluent.

Table 7.1. Disinfection processes in less common use

Process	Comments
Chloramination	• produced by dosing ammonia and chlorine together • slow reacting and requires a longer contact time • used in potable water disinfection • virus removal is reported to be unsatisfactory
Chlorine Dioxide	• has to be generated on site using sodium chlorite • is used in potable water disinfection • halogenated organic compounds are not produced to any appreciable extent. • forms other potentially harmful by-products which are still being assessed. • effects on aquatic life are said to be less adverse than chlorine
Bromine Chloride	• has had very limited use in wastewater disinfection - mainly in the US • operating costs similar to chlorine • the major advantage is its efficiency over a wide temperature and pH range • residual is short-lived
Paracetic Acid	• used in the food industry • possibility of toxic environmental effects yet to be established • not available in Australia

Process	**Comments**
Lime	• disinfection occurs by microbial adsorption onto the precipitate (which is then removed by sedimentation) and also the effect of high pH • basis of the *Clarifloc* process which has been used with some success in the UK • also removes BOD, turbidity and phosphorus • requires a holding period of 24 hours at pH above 12.5 - usually not economical or practical • disposal costs of sludge produced from sedimentation needs to be considered
Pasteurisation	• requires temperatures of 100 to 120 °C • high energy costs associated with heating large volumes of effluent make it uneconomical
Hydrogen Peroxide	• has been used for odour control and to inhibit microbial growth in sewers • a strong oxidant but a poor disinfectant
Potassium permanganate	• use in effluent disinfection very limited
Metal ion coagulation	• aluminium sulphate (alum) and ferric chloride are commonly used as coagulants in water treatment • coagulation can achieve good microbial removals • also removes BOD, suspended solids, turbidity and phosphorus • disposal costs of sludge produced from sedimentation needs to be considered
Electro-coagulation	• un-trialed on meat processing effluent
Gamma radiation	• uses a radioactive source such as cobalt 60 • reliable • leaves no chemical residual in effluent • safety risk • its use could raise political issues

7.2 Chlorination

7.2.1 Introduction

Chlorination has been the traditional method of disinfection employed in both water and wastewater treatment. The most common forms of chlorine used are gaseous chlorine, Cl_2, calcium hypochlorite, $Ca(OCl)_2$, sodium hypochlorite, NaOCl, and chlorine dioxide, ClO_2.

7.2.2 Chemistry

The addition of chlorine gas to water produces hypochlorous acid, HOCl, and the hypochlorite ion, OCl^-, which together form the free available chlorine. These reactions are described as follows:

$$Cl_2 + H_2O \leftrightarrow HOCl + Cl^-$$

$$HOCl \leftrightarrow H^+ + OCl^-$$

The balance between HOCL and OCl^- varies according to pH and temperature. At 20 °C and a pH of 7.5, the proportions are roughly equal. At the same temperature and a pH of 6, the proportion of HOCl increases to 97%; at a pH of 9, the proportion of HOCl reduces to 3%. This is significant in terms of performance since the disinfecting power of HOCl is markedly higher than that of OCl^-. Disinfection of effluent is therefore more effective at a lower pH.

The reactions for sodium and calcium hypochlorite are described as follows:

$$Ca(OCl)_2 + 2H_2O \rightarrow 2HOCl + Ca(OH)_2$$

$$NaOCL + H_2O \rightarrow HOCl + NaOH$$

From the above reactions, it can be seen that addition of chlorine gas causes a lowering of pH, whereas addition of hypochlorite salts causes a rise in pH. On a mass-for-mass basis of chlorine added, disinfection is more effective with gaseous chlorine. A disadvantage with hypochlorite salts is the increase in total dissolved solids (TDS).

7.2.3 Design issues

Chlorine is a potent oxidising agent and will react with organic material and ammonia present in the effluent. These reactions impose a chlorine demand which must be satisfied before a free, available chlorine concentration can be established. The reaction with ammonia produces *chloramines* which also have a disinfecting capability, although very slow in reacting.

The principal factors in achieving effective disinfection are:

- initial mixing - chlorine dosed into a highly turbulent flow will achieve a reduction in microbial numbers some two orders of magnitude greater than if dosed into a completely mixed tank

- contact time - in general, the longer the contact time, the greater performance. The contact time may be a parameter specified in the environmental authority (license) and is generally in the range of 15 to 45 minutes.

- chlorine residual - generally in the order of 0.5 mg/L.

7.2.4 Process considerations

Process issues that need to be considered in chlorination include:

- Alkalinity
  The reaction with ammonia produces Hydrochloric acid (HCl) and causes a reduction in the effluent alkalinity of approximately 15 mg/L for each mg/L of ammonia reduced. This will have little significance unless the wastewater alkalinity is unusually low.

- Increase in total dissolved solids (TDS)
  Chlorination results in an increase in effluent TDS and this is a factor that needs to be considered if effluent re-use is being contemplated.

- Environmental Policy
  Concern over the effects of chlorine on aquatic life and the possible discharge of chlorinated hydrocarbons to the environment has led to a review of policy on disinfection in some states, particularly with respect to the use of chlorine as the preferred option. Effluent can be de-chlorinated to remove residual chlorine by the addition of either sulfur dioxide or sodium metabisulfite. However, the process requires mechanical equipment and additional tankage, all of which adds to the cost.

7.2.5 Safety issues

Chlorine is an extremely hazardous chemical. All users should prepare an emergency plan and carry out periodic practice drills to ensure that all personnel know what to do in an emergency. A handbook on chlorine is produced by Orica Chemicals[1] who can advise on safety issues.

Chlorine gas is heavier than air and will accumulate at floor level in unventilated areas. For this reason, enclosed chlorine storage areas must be well vented at all times, with the vents extending down to floor level. The Australian Standard, AS 2927, details the requirements for storage and handling of chlorine gas. Breathing apparatus should be provided for use in emergencies. Personnel working with chlorine gas must be trained in the correct techniques for handling and connecting up chlorine containers.

7.2.6 Forms commercially available

Gaseous chlorine is supplied in supplied in 70 kg cylinders and 1 tonne drums. Calcium hypochlorite is supplied in granular form and is possibly the most dangerous form of chlorine. It is unstable, can generate intense heat and can explode or ignite if contaminated with other materials.

Sodium hypochlorite is supplied as a liquid and has positive advantages:

- reliability
- low cost
- ease of operation & maintenance
- significantly less hazardous than gaseous chlorine

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[1] Orica Chemicals Customer Service Centre
Tel. 1300 550 036
Fax. 1300 550 081

7.2.7 Dosage requirements

Chlorine dosage requirements vary according to the level of wastewater treatment provided - indicative values are shown in Table 7.2.7 (Qasim, 1986).

Table 7.2.7. Indicative values of chlorine dosage

Level of wastewater treatment	Dosage (mg/L)
Untreated wastewater	6 - 25
Primary treatment	5 - 20
Secondary treatment	2 - 8
Tertiary treatment	1 - 5

7.2.8 Disinfection efficiency

As noted previously, the effectiveness of disinfection will vary according to the level of treatment provided upstream. Table 7.2.8 (Qasim, 1986) shows typical coliform counts that can be achieved with different levels of treatment.

Table 7.2.8. Micro-organism numbers remaining at various chlorine residuals

Total chlorine residual (mg/L)	Total coliform count (/100 mL)	
	Primary effluent	Secondary effluent
0.5 - 1.5	24×10^3 - 400×10^3	10^3 - 12×10^3
1.5 - 2.5	6×10^3 - 24×10^3	200 - 10^3
2.5 - 3.5	2×10^3 - 6×10^3	60 - 200
3.5 - 4.5	10^3 - 2×10^3	30 - 60

7.2.9 Potential problems with the disinfection of meat processing effluent

Meat processing wastewater generally has much higher levels of organic matter, nitrogenous compounds and phosphates than domestic wastewater. This is evident from the comparison in Table 7.2.9.

Table 7.2.9. Comparison of meat processing and domestic wastewaters

Characteristic (raw wastewater)	**Typical range (mg/L)**	
	Meat processing	**Domestic sewage**
COD†	2,000 - 6,000	350 - 1,000
Total-N	100 - 250	30 - 80
Total-P	20 - 50	6 - 30

† Chemical oxygen demand - a parameter that reflects the amount of organic matter present in the wastewater.

Chlorine will react with any organic and nitrogenous compounds that may be present in the effluent. This presents two issues that need to be considered:

- a quantity of chlorine will be consumed in the reaction with these compounds and additional chlorine will have to be added to achieve the "free" concentration required for disinfection. The high levels of organic and nitrogenous compounds present in meat processing effluent will increase the consumption of chlorine substantially. This consumption, also referred to as a "demand", will therefore result in a significant increase in operating costs.

- the reaction between chlorine and organic and nitrogenous compounds can result in the formation of toxic by-products which include *trihalomethanes* (THMs) which are a major concern in the water industry. The high levels of organic and nitrogenous compounds present in meat processing effluent will result in increased levels of these by-products which may well exceed acceptable limits. If this is the case, chlorination may not be an acceptable form of disinfection for meat processing effluents. This is an issue that requires further study.

7.2.10 Process flow sheet - gaseous chlorination

A typical process flow sheet for gaseous chlorination is shown in Figure 7.2.10.

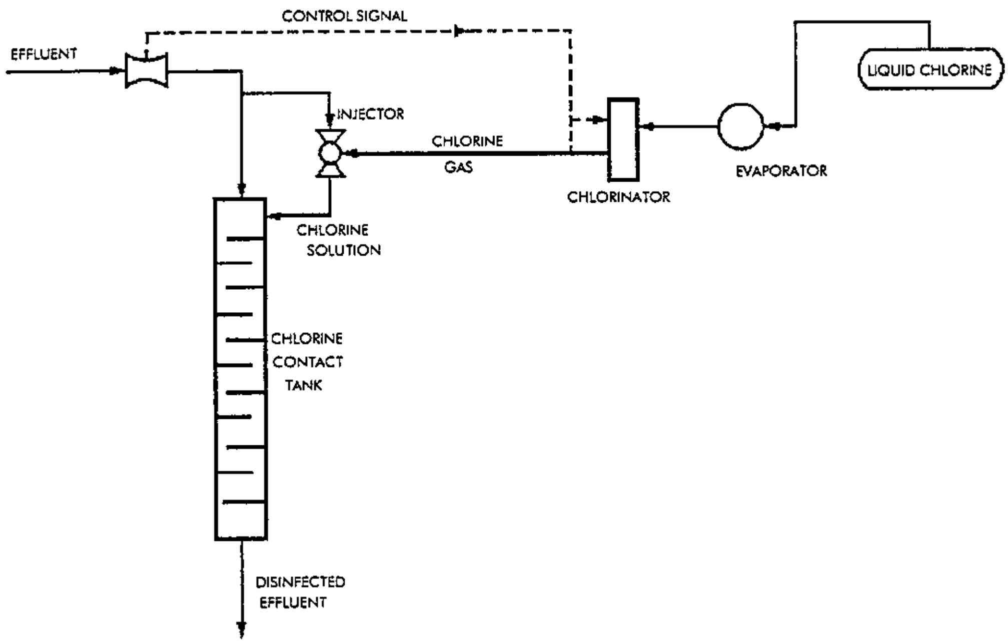


Figure 7.2.10 Process flow sheet for gaseous chlorination.

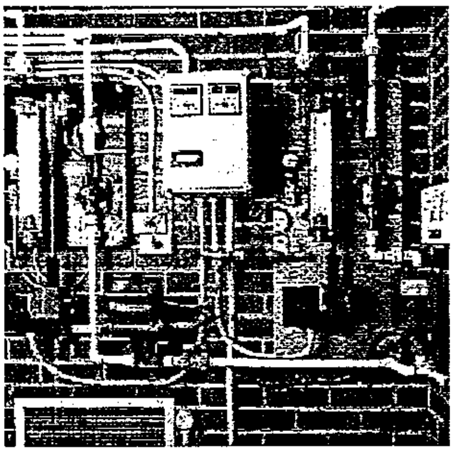
7.2.11 Cost- gaseous chlorination

Infrastructure requirements for gaseous chlorination include:

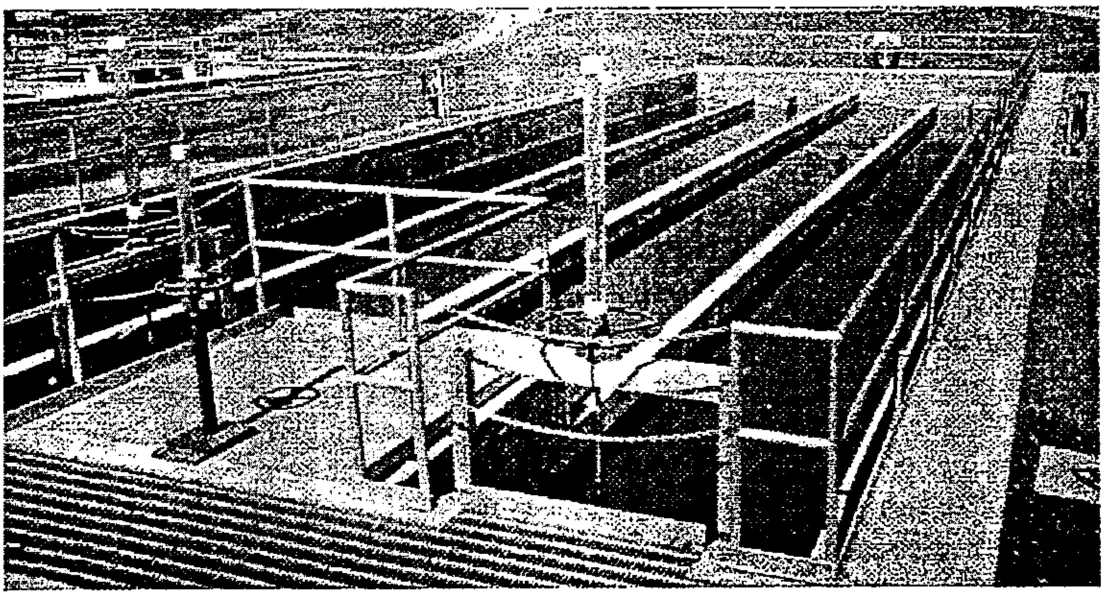
- a contact basin - a concrete tank or an earthen lagoon, of sufficient volume to provide 15 to 45 minutes retention
- a gas cylinder store or fenced enclosure
- a chlorinator
- dosing lines

Figure 7.2.11 shows the various components of a chlorine dosing system.

(a) chlorine cylinders
Source: Orica Chemicals



(b) chlorinator
Source: Orica Chemicals



(c) chlorine contact tank
Source: Metcalf & Eddy, 1991

Figure 7.2.11. Photographs showing components of a chlorine disinfection system.

Order-of-magnitude costs for a 1 ML/day plant and a 3 ML/day plant are shown below.

Component	**1 ML/day**	**3 ML/day**
Mechanical & electrical equipment	$5,000	$5,000
Civil engineering work	$500,000	$800,000
Total cost	$505,000	$805,000

7.2.12 Process flow sheet- sodium hypochlorite

A typical process flow sheet for sodium hypochlorite disinfection is shown in Figure 7.2.12.

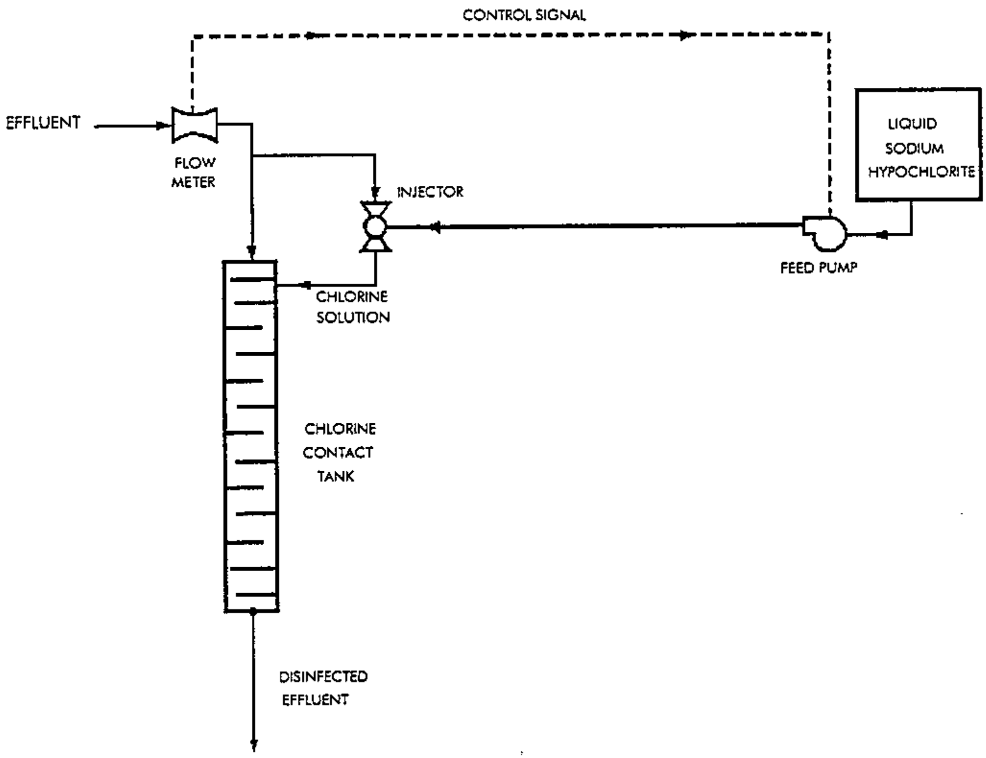


Figure 7.2.12 Process flow sheet for sodium hypochlorite disinfection.

7.2.13 Cost- sodium hypochlorite

For a sodium hypochlorite system, infrastructure requirements would include:

- dosing pumps
- dosing lines and accessories
- contact tank

Order-of-magnitude costs for a 1 ML/day plant and a 3 ML/day plant are shown below.

Component	1 ML/day	3 ML/day
Mechanical & electrical equipment	$1,000	$2,000
Civil engineering work	$500,000	$800,000
Total cost	$501,000	$802,000

Maintenance requirements are usually minimal so that for practical purposes, the operational cost can be taken as the cost of supply. Current (1999) supply costs, on a pure chlorine basis, are:

- gaseous chlorine $1,400/tonne Cl_2
- sodium hypochlorite $2,300/tonne Cl_2

As an example, operating costs for a chlorine dose of 5 mg/L would be as follows:

Chlorine form	1 ML/day	3 ML/day
Gas	$2,550	$4,200
Sodium hypochlorite	$7,650	$12,600

A photograph of a sodium hypochlorite dosing facility is shown in Figure 7.2.13.

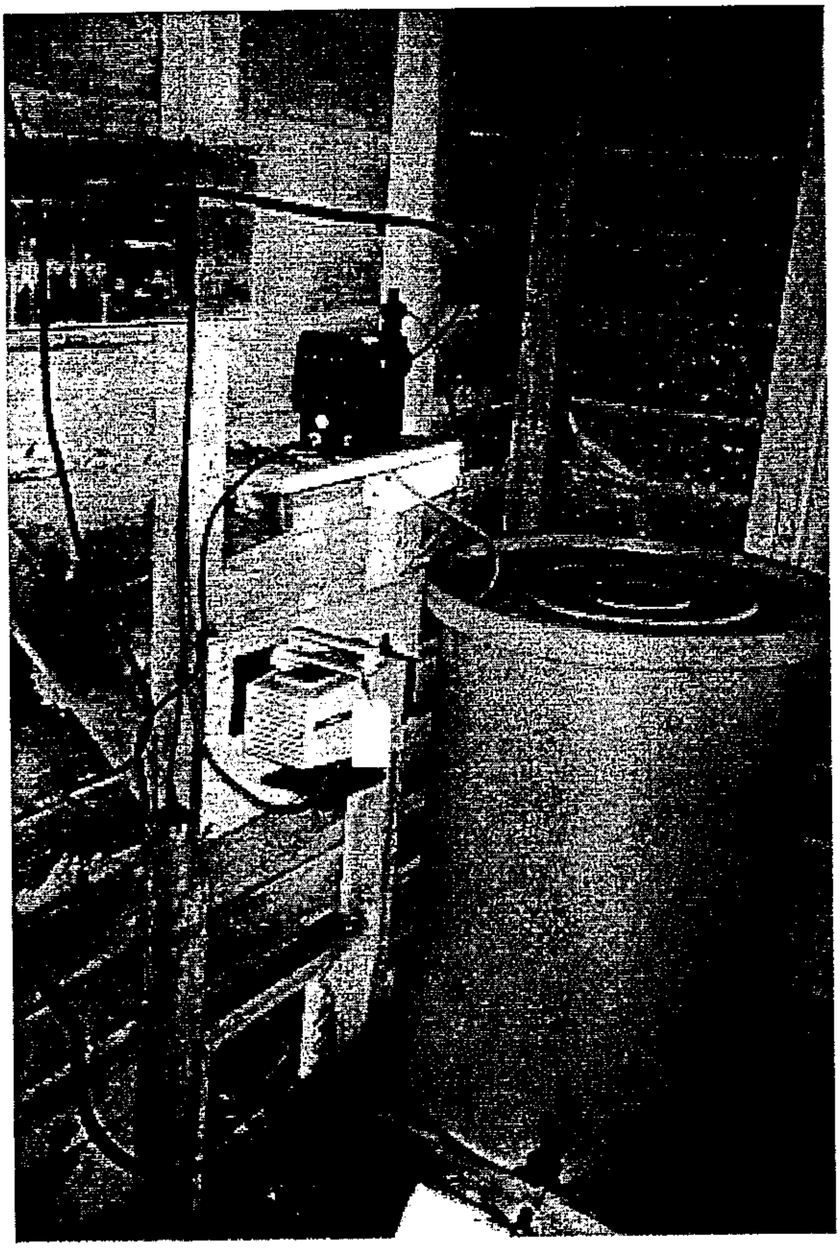


Figure 7.2.13 Photograph of a sodium hypochlorite dosing facility.

7.3 Ozone

7.3.1 Introduction

Ozone is an unstable form of oxygen and has to be generated from dry air or oxygen. It is highly reactive, a stronger oxidising agent than chlorine, and considered one of the most effective chemical disinfectants available. Ozone has been used in Europe and the USA as a disinfectant since the 1970's. The early equipment suffered from operational problems but these have been largely overcome with experience, research and development. Ozone has not had extensive use in Australia and at present there are very few installations.

7.3.2 Chemical symbol

The chemical symbol for ozone is O_3; oxygen is O_2.

7.3.3 Production

The strong reactivity of ozone makes it unsuitable for storage and it is has to be generated on site. The method of production involves the discharge of high voltage electricity between electrodes. Under these conditions, oxygen molecules split and reform with other oxygen molecules to produce ozone molecules. Ozone production from oxygen ranges from 4 to 10 % $^w/_w$ whereas with air, production is in the range of 1.5 to 3 % $^w/_w$. For ozone doses up to 5 mg/L, air fed systems are more efficient. With air fed systems, the air has to be filtered and dried to at least -60°C pressure dew point and this is carried out with refrigerated coolers and pressure swing dryers. With oxygen fed systems, the oxygen is either derived from liquid oxygen or generated on site.

7.3.4 Safety issues

Ozone is an extremely poisonous gas and personnel involved in the operation and maintenance of the generating equipment must be trained in the appropriate safety procedures.

7.3.5 Process Considerations

Positive aspects relating to ozone is that its use does not affect alkalinity or cause an increase in total dissolved solids. In addition to disinfection, the powerful oxidising properties of ozone enable the removal of colour, taste and odour and the oxidation of a wide range of organic compounds.

7.3.6 Disinfection Efficiency

Destruction of bacteria and viruses is rapid compared with chlorine which requires a long contact period. Ozone is more effective in virus removal than chlorine, however, there have been reports that it is less effective against certain strains of bacteria.

7.3.7 Dosage Requirements

It is not possible to maintain a residual concentration with ozone because of its high reactivity and low solubility. Ozone rapidly decomposes to oxygen and this helps maintain a dissolved oxygen level in the purified water. The recommended dose is 10 mg/L and the residual in the contact tank should be maintained at between 0.1 and 0.2 mg/L.

7.3.8 Injection

There are several forms of distribution system available for dosing ozone but the two most commonly used are fine bubble diffusers and sidestream vacuum injectors. Fine bubble diffuser systems consist of a grid of ceramic diffusers installed on the floor of the contact tank. The minimum depth of the contact tank is 5 metres - which implies high construction costs. Diffuser systems can be prone to operational problems such as clogging by contaminants or precipitated salts. Diffuser systems are most economic where the dose rate exceeds 3 kg/hour.

Vacuum injectors are more efficient but have a higher energy consumption. The system operates by pumping water into the injector, which draws the ozone/gas mixture from the ozonator at sub-atmospheric pressure. The injectors produce very small bubbles which enables a high transfer efficiency to be achieved. Injector systems are most economic for dose rates up to 3 kg/hour.

To achieve disinfection, ozone has to be dosed into at least two separate contact tanks or compartments, each requiring its own distribution system. Contact tanks are normally constructed in concrete and are similar in layout to the contact tank used in chlorination systems. With diffuser systems, foaming and scum formation can occur and some form of removal system may be required.

7.3.9 Off-gas Destruction

Some ozone will escape into the air above the contact tank (the off-gas) and this has to be captured and destroyed. Ozone is extremely toxic, with a human exposure limit of 0.1 ppm. There are several processes available for ozone destruction but only two are considered suitable in effluent treatment applications - thermal destruction and thermal/catalytic destruction. With both processes, the off-gas first has to be passed through a water/mist eliminator.

Thermal destruction processes heat the off-gas to a temperature of 350 °C at which point ozone rapidly breaks down. As would be expected, the process has a high energy consumption.

Thermal/catalytic destruction processes employ a metal catalyst to convert the ozone to oxygen. The off-gas is heated to 60 °C to prevent condensation forming on the catalyst bed. Energy consumption is high, although not as high as in thermal destruction processes.

7.3.10 Process Control

Ozone dosing systems require a control system to monitor the effluent flow rate and the ozone residual in the contact tank. The ozone dose is normally paced to the effluent flow rate and controlled via a 4-20 mA signal from a flow meter. Dissolved ozone monitoring equipment is used to monitor the ozone residual in the contact tank and control the ozonator.

7.3.11 Infrastructure

Ozone generating equipment would normally be housed within a building and, because of corrosion problems, all metal work and piping needs to be fabricated from stainless steel. The installation would typically consist of:

- for an air fed system - an air preparation unit; for an oxygen fed system - an oxygen generator or bulk liquid oxygen installation
- distribution system - diffusers or vacuum injectors
- a covered concrete contact tank
- a foam removal system
- off-gas destruction - a thermal or catalytic/thermal unit
- control system
- pipework
- building

Figure 7.3.11 (a) shows a typical flow sheet for an ozone disinfection system. Figures 7.3.11(b) and (c) show photographs of ozone generating plants.

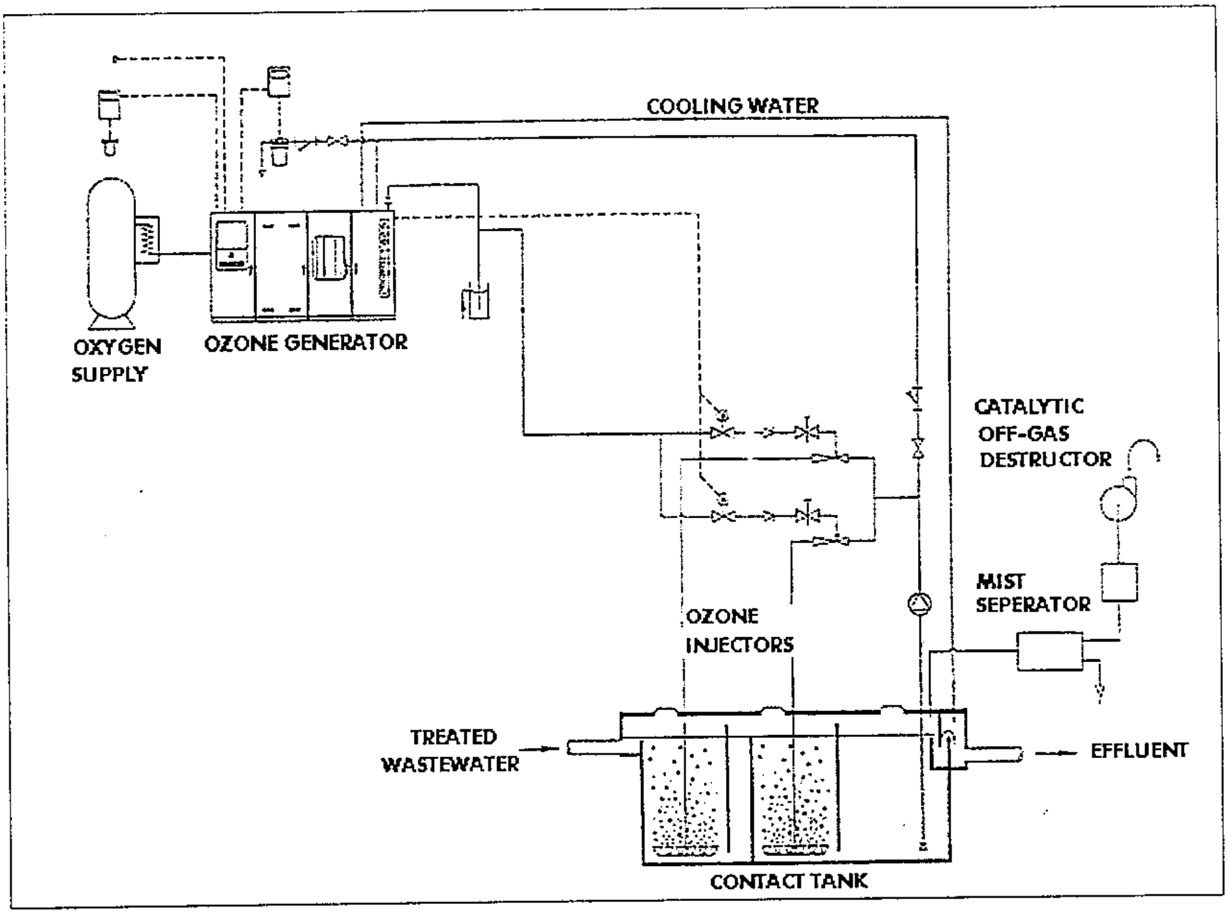


Figure 7.3.11. Process flow sheet for an ozone disinfection system.
Source: Ionics Watertec

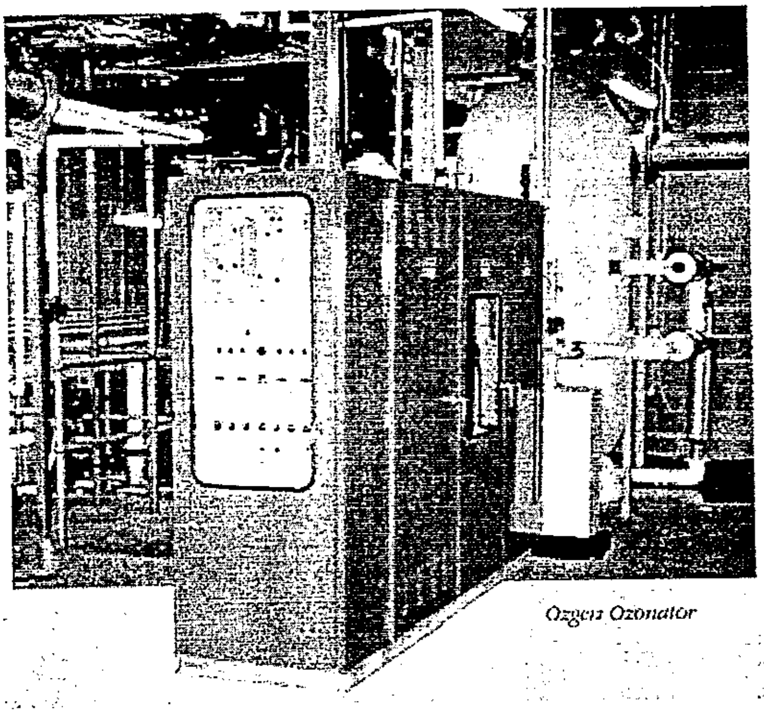


Figure 7.3.11(b). Photograph of an ozone generation plant.
Source: Ionics Watertec

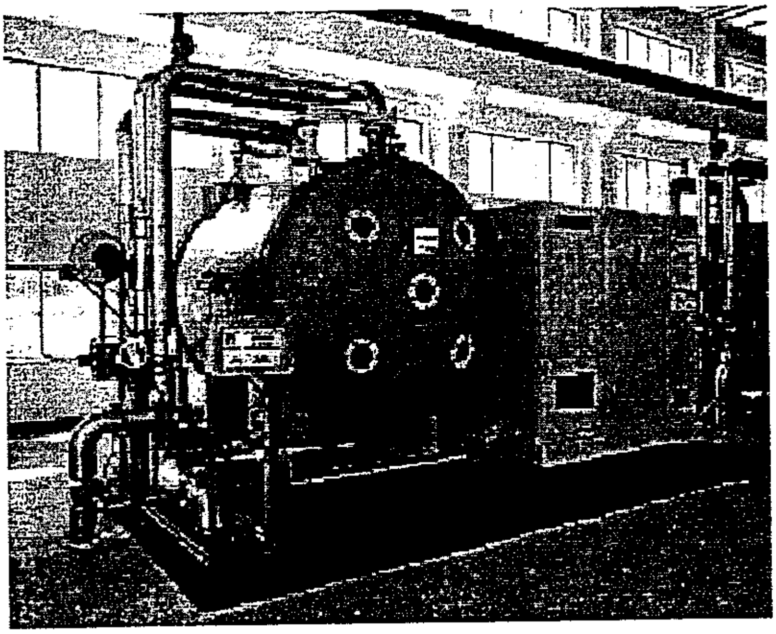


Figure 7.3.11(c). Photograph of an ozone generation plant.
Source: Wedeco

7.3.12 Potential problems with the disinfection of meat processing effluent

The potential problems associated with the chlorination of meat processing effluents also apply to ozone. Ozone will react with any organic and nitrogenous compounds that may be present in the effluent and the same issues need to be considered:

- a quantity of ozone will be consumed in the reaction with these compounds and additional ozone will have to be added to achieve the "free" concentration required for disinfection. The high levels of organic and nitrogenous compounds present in meat processing effluent will increase the consumption of ozone substantially. This consumption, also referred to as a "demand", will therefore result in a significant increase in operating costs.

- the formation of toxic by-products is reported to be less with ozone compared to chlorine, however, further research is needed to confirm this. The possibility needs to be considered that the levels of toxic by-product formed may exceed acceptable limits. If this is the case, ozone may not be an acceptable form of disinfection for meat processing effluents. Again, this is an issue that requires further study.

7.3.13 Cost

Compared to chlorination systems, the capital cost of ozone generating equipment is high. Until recently, ozone generators were only manufactured overseas and with added importation costs, this has not been an economic option. More recently, however, Australian companies have begun to manufacture ozone generators, such Ionics Watertec, with units capable of supplying municipal treatment plants of up to 7 ML/day. This has reduced the capital cost of equipment to some extent but the overall cost remains high.

Order-of-magnitude costs for two systems - one for a 1 ML/day plant, the other for a 3 ML/day plant are shown below.

Component	**1 ML/day**	**3 ML/day**
Mechanical & electrical equipment	$200,000	$300,000
Civil engineering work	$750,000	$1,200,000
Total cost	$950,000	$1,500,000
Operation & Maintenance (annual cost)	$20,000	$75,000

7.4 Continuous Membrane Filtration

7.4.1 Introduction

Continuous Membrane Filtration (CMF) is an emerging technology available in a variety of forms including reverse osmosis, ultrafiltration, nanofiltration and microfiltration. These technologies provide a physical means of disinfection with excellent removals. The range of technologies and their removal capabilities are shown in Figure 7.4.1.

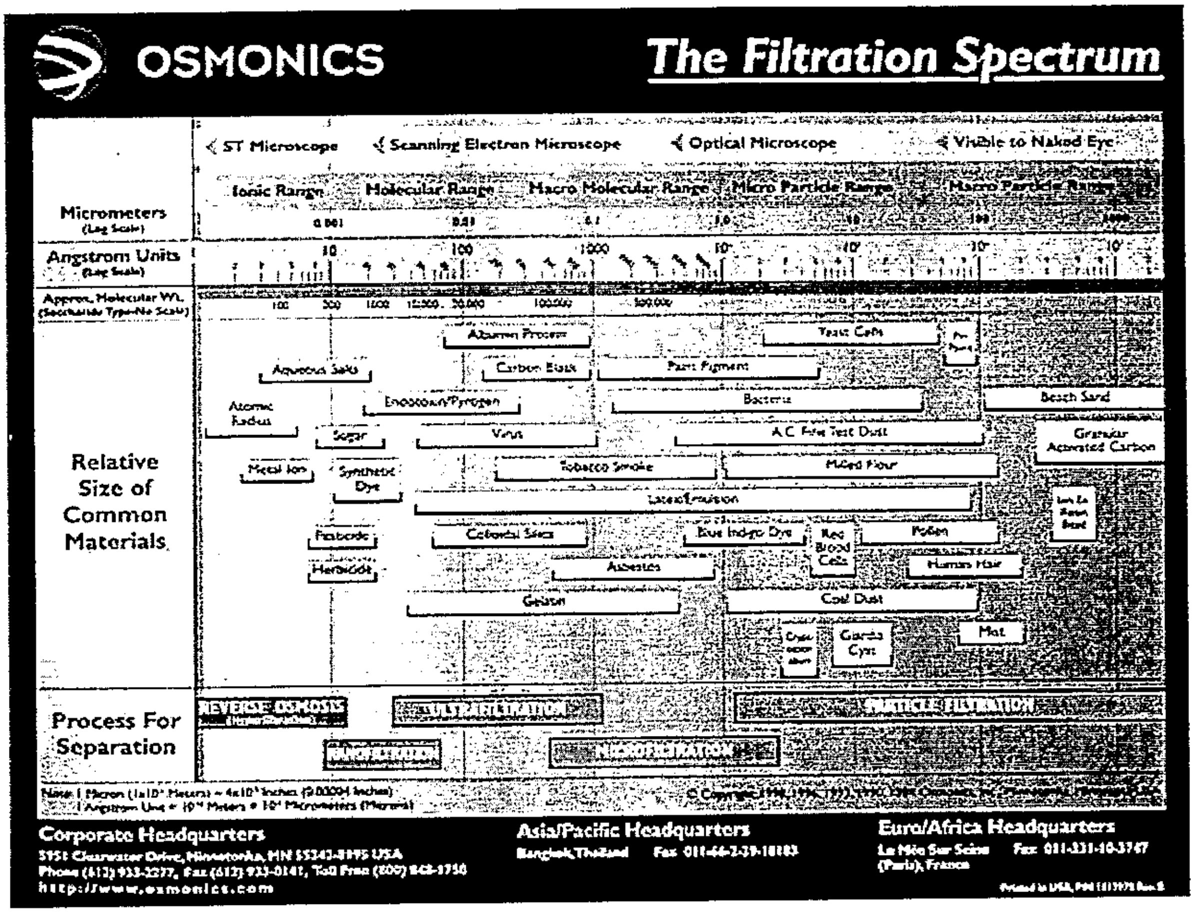


Figure 7.4.1. The Filtration Spectrum
Source: Osmonics

It can be seen that removal of bacterial can be achieved with microfiltration. For removal of bacteria and viruses, ultrafiltration is required.

7.4.2 Reverse Osmosis

In the Reverse Osmosis (RO) process, the feed water is forced through a membrane under high pressure. Purified water passing through the membrane is termed the permeate; material retained on the membrane is the concentrate and must be treated by a separate process. The operating pressure is high - normally within the range of 2,000 to 6,000 kPa. Removal efficiency for inorganic salts is in excess of 90 %. Suspended solids, colloidal matter, bacteria and viruses are almost totally removed. Removal efficiency is lower for some organic compounds such as phenols. Water recovery varies from 50 to 85 % depending on the type of membrane used, the applied pressure and the temperature and quality of the effluent feed.

Membranes are manufactured from various materials, each of which has its own characteristics and limitations. Modified cellulose acetate has been widely used but suffers from biological degradation and can only be used in a pH range of 3.5 to 7.5. More recently developed are membranes made from polyamide and polysulphone. These membranes are capable of higher throughput, can operate in a pH range of 3 to 11 and have a higher resistance to chemical and biological attack. Polyamide membranes, however, are susceptible to attack by free chlorine. This is a severe disadvantage because disinfection is usually carried out before reverse osmosis to prevent biological growth on membranes.

Membranes are supported in what is known as a permeator - the permeator also serves as a conduit feeding water to the face of the membrane and collecting the permeate on the other side. Various types of permeator have been developed and are available in forms known as tubular, spiral wrap and hollow fibre. The volume of concentrate varies between 15 to 50 % of the feed flow and consideration needs to be given to the method of treatment and disposal.

7.4.3 Ultrafiltration

Ultrafiltration is similar to reverse osmosis but operates at a lower pressure. The system employs a coarser membrane which produces a good removal of suspended solids, colloidal material and high molecular organics and near total removal of bacteria and viruses. Removal of inorganic salts however, is less efficient. Membranes are manufactured from synthetic polymers and have the advantage that they can be handled dry and used with organic solvents. Permeators are similar to those used in reverse osmosis.

Operating problems generally relate to the build up of concentrate which causes a reduction in throughput. These problems can be overcome by utilising high feed velocities parallel to the membrane surface.

7.4.4 Nanofiltration

Nanofiltration is a relatively recent development and employs a variation of the reverse osmosis membrane. Similar removals are achieved for soluble organic compounds, the passage of mono-valent salts is higher while the passage of di-valent salts is significantly lower. As the major portion of osmotic pressure is required for mono-valent salts, this results in a substantial reduction in energy requirements and hence operating cost.

7.4.5 Microfiltration

Microfiltration is a low pressure membrane filtration process which has excellent and reliable removal of turbidity, bacteria and cysts, good removal of viruses but has poor removal of true colour and other dissolved contaminants. The process does not remove total dissolved solids, hardness or dissolved metals.

7.4.6 Applications in the meat processing industry

Some research work has been carried out in South Africa (Cowan, *et al*, 1992, Jacobs, *et al*, 1993 and Bouckaert, *et al*, 1999) to assess the performance of ultrafiltration on abattoir effluent. It is worth reviewing the reports on this work because ultrafiltration could prove to be a better alternative to the disinfection technologies already considered.

The reports note that abattoir effluent contains numerous proteinaceous and fatty constituents which will inevitably coat the membranes and cause fouling. Pretreatment steps such as screening and dissolved air flotation to remove fat and other bulky materials are therefore essential. Wedge-wire screens were found to perform best. Rotary screens were not as efficient in the removal of fibrous material and occasionally let through fragments of meat and bone. It was found that long fibres tended to get caught in the return bends that connect the ends of the membrane tubes. This produced a fibrous plug which then trapped pieces of tissue and bone and ultimately led to blockage. Trials were carried out with different cleaning agents used in the meat processing industry and the findings are summarised as follows:

- the melting point of fatty deposits appeared to be approximately 51°C.
- low temperature rinsing (21°C) with cleaning solutions was not as effective as medium temperature (50°C) rinsing. [a steam heater was used to pre-heat the cleaning agent]
- foamballs inserted into the membrane tubes produced a scouring action and were very effective in loosening the deposits, particularly if air was introduced. [specially designed balls made from foam (sponge) were manually inserted into the tubes]
- proteolytic enzyme cleaners used in the meat processing industry were effective in breaking up the deposits on the membranes
- restoration of membrane performance was improved when enzyme cleaning was followed by a chloralkali rinse

The research work involved both laboratory and pilot plant trials and performance was summarised as follows:

Parameter	Removal achieved (%)
COD	90-93
Phosphorus	85
Salinity	25

Removals for micro-organisms were not reported, however, it has already been noted that utlrafiltration achieves near total removal of bacteria and viruses present in the effluent. Removal of soluble phosphate was reported to be consistent and it was speculated that this was possibly as a result of complexing with proteinaceous material. The removals shown for COD, phosphorus and salinity suggest that ultrafiltration might offer other opportunities in addition to disinfection. There is the possibility that an ultrafiltration unit could also perform the role of a nutrient-removal process. Furthermore, with a reduction in salinity, the effluent would be more acceptable for irrigation. These possibilities are worthy of further investigation.

7.4.7 Process flow sheet

A typical process flow sheet is shown in Figure 7.4.7.

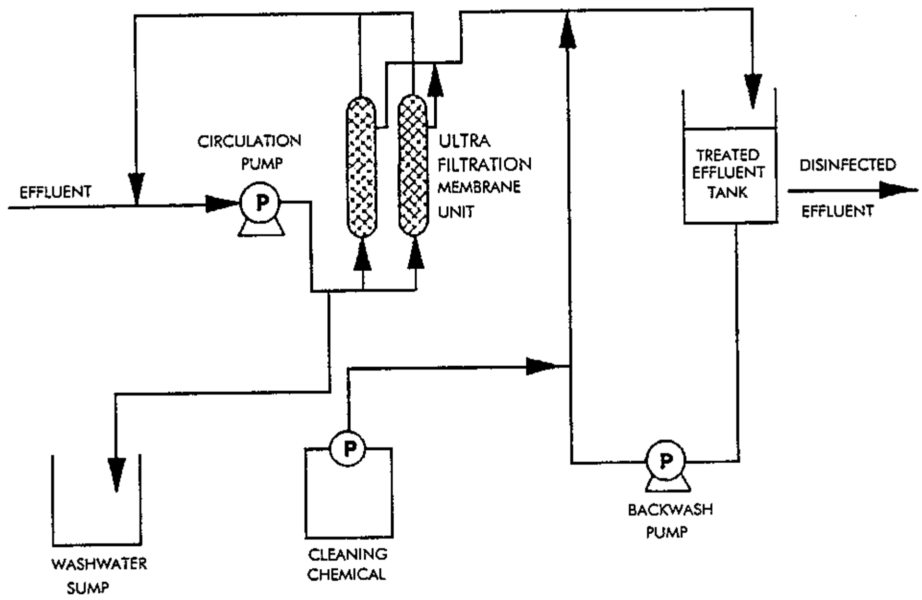


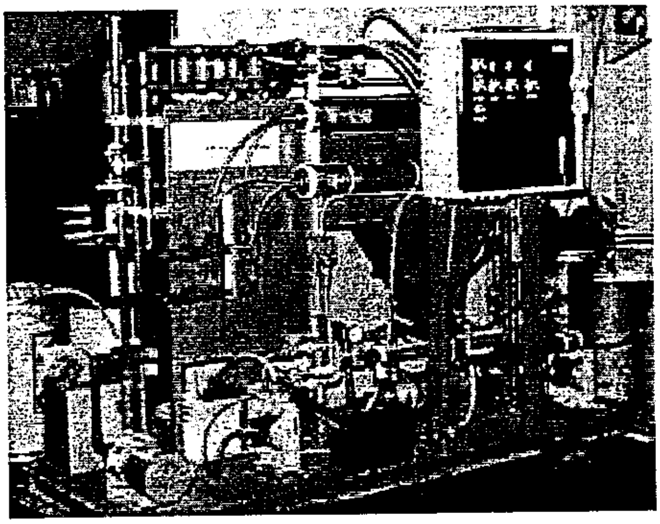
Figure 7.4.7. Process flow sheet for ultrafiltration

7.4.8 Cost

In comparison to a chlorination system, the capital cost of membrane filtration unit is high. A membrane process will require considerably more maintenance than a chlorination system and operational costs can be expected to be significantly higher. Order-of-magnitude costs for two systems - one for a 1 ML/day plant, the other for a 3 ML/day plant are shown below.

Component	**1 ML/day**	**3 ML/day**
Mechanical & electrical equipment	$350,000	$1,200,000
Civil engineering work	$800,000	$900,000
Total cost	$1,150,000	$2,100,000
Operation & Maintenance cost (per annum)	$40,000	$110,000

Figure 7.4.8 contains photographs of ultrafiltration units.



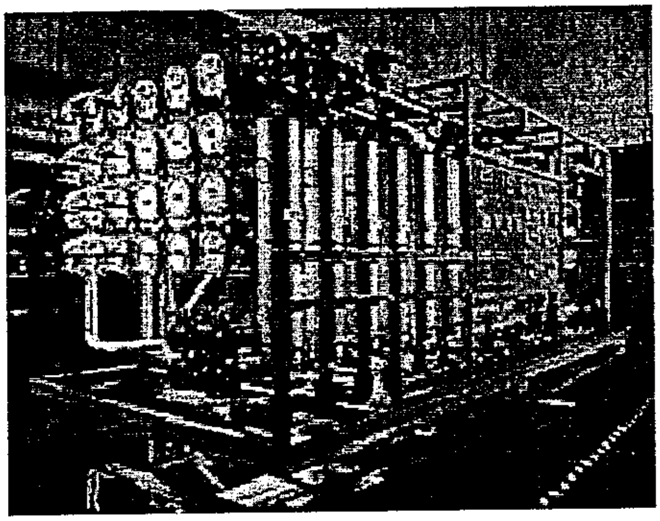


Figure 7.4.8. Photographs of ultrafiltration units.
Source: Osmonics

7.5 Ultra violet (UV) irradiation

7.5.1 Introduction

UV disinfection is seeing increasing use at municipal sewage treatment plants as an alternative to chlorination. UV disinfection does not provide a residual as with chlorination and, from an environmental perspective, there is the view that this creates less harm in the discharge of effluent to aquatic environments. However, it does require a very effective 'kill' as disinfection ceases on exiting the UV system.

7.5.2 Mechanism of disinfection

The mechanism of microorganism inactivation occurs through the destruction of cellular material such as the nucleic acids DNA and RNA by UV radiation. UV disinfection has been shown to be effective against bacteria and viruses. Its effectiveness against protozoa and helminths has still to be determined.

The effectiveness is dependant on the radiation intensity, the contact time with the effluent and the exposure of the microorganisms to the radiation. Successful operation requires an effluent with high light transmissivity i.e. low suspended solids, low colour and a turbidity of less than 5 NTU. Suspended solids can shield micro-organisms from radiation and some can be reactivated if exposed to sunlight.

7.5.3 Process Description

Mercury arc lamps are the most commonly used source of UV radiation. Normally a concrete channel is constructed to provide the right hydraulic conditions and the lamps are submerged directly in the effluent. The lamps are held in racks arranged side by side within the channel and individual racks can be lifted out for cleaning.

The sleeve surrounding the lamp reduces the transmittance by 50 % or more and this will further reduce with the length of interval between cleaning. The temperature of the surface of the lamp, also affects performance, the optimum temperature being in the range of 40 ° to 50 °C. Outside of this range, efficiency can drop by as much as 2 % per °C. Efficiency also reduces with the life of the lamp by up to 75 % of the output when new. Lamp life can vary between 7,500 and 13,000 hours.

A large quantity of research data has been published from the numerous laboratory studies and pilot plant trials that have been carried out. However, the success often reported has not always been replicated in full scale installations. UV disinfection units have now been installed at a number of wastewater treatment plants in Australia. Problems that have emerged include higher than expected power demands and difficulty in meeting the licence requirements.

Many of these problems can be attributed to effluents with a low transmissivity or the formation of scale on the lamps. In respect to meat processing wastewaters, this is likely to be a major problem.

7.5.4 Potential problems with the disinfection of meat processing effluent

The performance of a UV disinfection unit is dependant on the extent to which the UV light is able to penetrate the effluent. This property is termed the "transmissivity" and is generally measured as a percentage. A transmissivity of 100 % would indicate perfect conditions for UV disinfection. On the other hand, a transmissivity of 20 % would indicate unfavourable conditions for UV disinfection. With domestic effluent, transmissivity has been found to vary from one site to another to such an extent that it has not been possible to establish an average value. This will also apply to meat processing effluents. Experience has shown that the transmissivity of an effluent can not be assumed - it has to be measured.

The transmissivity of an effluent is affected by various factors which include the level of suspended solids, colour, turbidity, dissolved solids, fat and grease. Even with good quality domestic effluent, problems have been experienced with colour and the precipitation of salts on the lamps. With meat processing effluent, factors that are likely to cause problems are high levels of :

- suspended solids
- fat and grease
- salinity

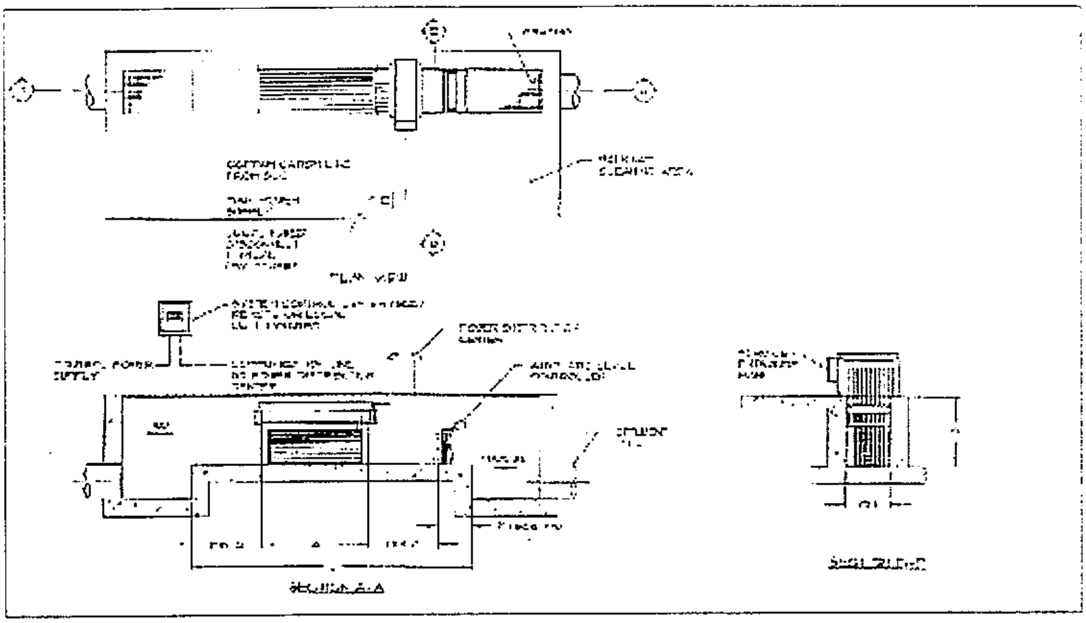
Effluents with low transmissivities require more lamps and thus more energy. From experience it has been found that for effluents with a transmissivity lower than 30%, UV disinfection is no longer an economic proposition.

7.5.5 Cost

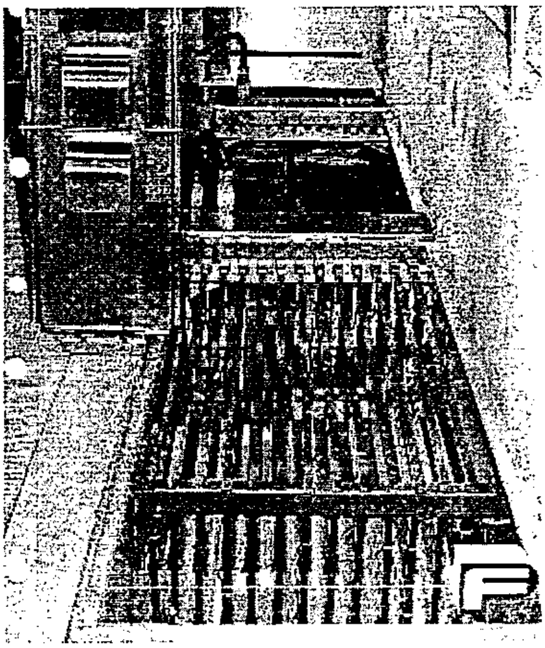
UV disinfection units are installed in purposely designed reinforced concrete channels and the installation will typically include:

- Lamp assembly units
- Lamps
- Switchboard, level control and PLC or microprocessor based control system
- Electrical power supply
- Transmittance monitor
- Cleaning system

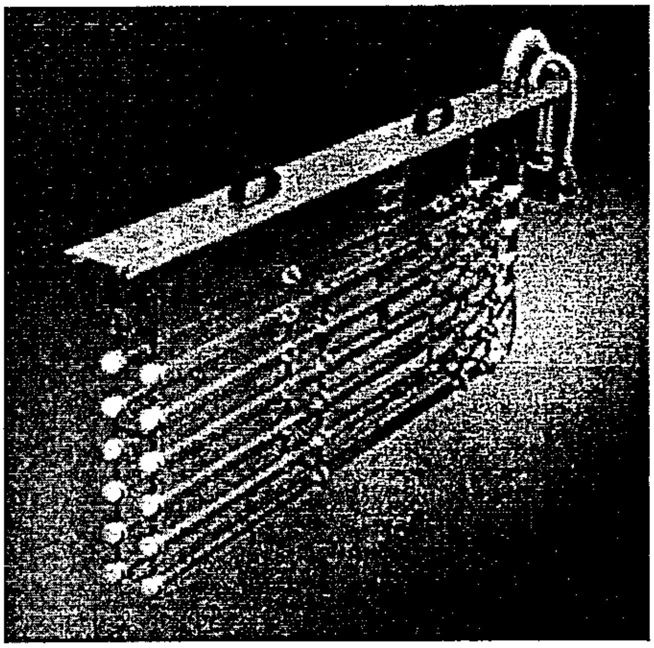
Figure 7.5.5 shows a typical UV installation and a lamp assembly unit.



a) Drawing of a UV installation (Source: Trojan Technologies



(b) photograph of a UV installation
(Source: Fischer & Porter)



(c) photograph of a UV lamp assembly
(Source: Wedeco)

Figure 7.5.5. Components of a UV system

As it has been already noted, the transmissivity of an effluent can vary over a wide range and has to be determined on a site-by-site basis. For this reason, costs are extremely difficult to predict. However, based on information from domestic wastewater systems, order-of-magnitude costs for a 1 ML/day and a 3 ML/day plant are provided below.

Component	**1 ML/day**	**3 ML/day**
Mechanical & electrical equipment	$100,000	$150,000
Civil engineering work	$500,000	$800,000
Total cost	$600,000	$950,000

Operating costs will include:

Cost Component	**1 ML/day Unit**	**3 ML/day Unit**
Lamp Replacement The average lamp life expectancy is 13,000 hours (18 months). The number of lamps will depend on the effluent quality but, as an example, with 85 Watt lamps costing $120 each in the following numbers: The average annual replacement cost would be:	20 $1,600	60 $4,800
Power The cost of electrical power needs to be carefully evaluated, particularly if there is a commercial agreement with a power supplier. Some agreements are based on a flat tariff, others involve penalty rates if power usage exceeds an agreed level. It should be noted that the UV system will be required to operate continuously 24 hours per day so that taking advantage of off-peak tariffs is not an option. Furthermore, the quantity of power drawn will be in proportion to the effluent flow rate. Plants that experience peaks in flow will have a peak power demand unless some form of flow balancing is employed. In the example above, with a power cost of 15c/kWh, the average annual power cost would be:	$22,300	$67,000
Cleaning and Maintenance The frequency of cleaning is dependant on the characteristics of the effluent. In the example above, with a cleaning frequency of twice a week, ten minutes per lamp and a labour cost of $40/hour, cleaning costs would be:	$20,800	$62,400
Total	$44,700	$134,200

7.6 Electrochemical disinfection

/ ELECTROCOAGULATION (CARDIA)

7.6.1 Introduction

Electrochemical disinfection is *not* one of the main-stream disinfection technologies. However, the potential benefits that this process could offer are worthy of consideration.

Electrochemical disinfection has been patented in a number of countries (Porta and Kulhanek, 1986; Rumeau and Garnerone, 1979; Tiesler, 1985). It has been used in Australia primarily in the disinfection of domestic swimming pool water and in small scale potable water purification. It is now being marketed under the trade name *Positron* for disinfection of effluent from on-site domestic wastewater package plants.

The technology is currently under trial at the Brendale wastewater treatment plant, north of Brisbane. Electrochemical disinfection is reported to be capable of destroying a wide variety of microorganisms, including viruses, bacteria, algae as well as larger species (Gutknecht et al, 1981; Stoner and Cahen, 1982).

7.6.2 Process Description

Research has found that direct current is more effective than alternating current and good performance has been reported with Titanium electrodes (Porta and Kulhanek, 1986; Smith, 1972). Titanium is not harmful to human health and is not corroded by the alkali hydroxides or acids produced in the electrolysis of water (Cotton and Wilkinson, 1972). A build-up of a very thin Titanium oxide film occurs over time and additional voltage is required to maintain a constant current (Young, 1961). This can be overcome by alternating the polarity of the electrodes; film build-up on the anode is removed when polarity is reversed and the electrode becomes the cathode. This strategy keeps the electrodes clean and also reduces the power demand.

7.6.3 Mechanism of disinfection

The exact mechanism of disinfection is complex and not fully understood but it is thought that the following processes work in combination:

- Active oxygen atoms generated at the anode have a disinfecting capability but this is restricted to the vicinity of the electrode surface due to the short life of the oxygen radical:

$$2OH^- - 2e^- \rightarrow H_2O + [O]$$

$$2[O] \rightarrow O_2$$

- The electrolysis of water can produce ozone (Cotton and Wilkinson, 1972). It has been suggested (Porta and Kulhanek, 1986) that the following reactions occur:

$$O_3 + H_2O \rightarrow HO^+_3 + OH^-$$

$$HO^+_3 + OH^- \rightarrow 2HO_2$$

$$O_3 + HO_2 \rightarrow HO + 2O_2$$

The free radicals HO_2 and OH have a strong disinfective action, but over a short life. This implies that disinfective action could occur in the bulk volume of water, possibly with a slight residual action.

- The chloride ion Cl^-, almost always present in water, is oxidised to chlorine which reacts with water as follows (Porta and Kulhanek, 1986):

$$2Cl^- - 2e^- \rightarrow Cl_2$$

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

$$HOCl + H_2O \rightarrow H_3O^+ + OCl^-$$

Disinfection is affected by the species Cl_2, HOCl and OCl^- (Stoner and Cahen, 1982; White, 1972) and occurs in the bulk volume of water with a significant residual action.

- Oxidation of carbonate and sulphate ions present in the water may result in the formation of percarbonate and persulphate both of which are strong disinfectants (Porta and Kulhanek, 1986). This would have effect in the bulk volume of water with some degree of residual action.

- The reaction of molecular oxygen, O_2, with water can form hydroperoxide, another strong disinfectant:

$$O_2 + H_2O + 2e^- \rightarrow HO^-_2 + OH^-$$

Hydroperoxide ions being unstable and short-lived will decompose and have the potential to form active oxygen or hydroxide species as follows:

$$HO^-_2 \rightarrow OH^- + [O]$$

$$HO^-_2 + 2e^- + H_2O \rightarrow 3OH^-$$

This would occur in the bulk water volume but with little residual action.

- It has also been suggested that the electric field could have a disinfective action, causing electrochemical reactions to occur inside the micro-organisms (Porta and Kulhanek, 1986). This could occur in the bulk volume of water but would not have a residual effect.

There are also reports that the technology can remove ionic impurities such as sulphates, phosphates, chlorides, heavy metals and organic compounds (Porta and Kulhanek, 1986; Smith, 1972). The process is also reported to reduce turbidity and improve the taste and odour of water (Patermarakis and Fountoukidis, 1990). The removal of ionic species results in a softening of the effluent and this can have implications such as the leaching of calcium from concrete pipes, channels and tanks.

7.6.4 Practical Issues

The *Positron* process operates off a standard 220 volt AC supply which is then transformed to a DC current of less than one amp. The electrode assembly has to be mounted in a pipe and, depending on the flow rate, several units may be installed in series. It has been found that performance is improved if the disinfected effluent is retained for a period of two to six hours. This enables the various ionic species to disperse through the effluent and achieve a greater effect.

This technology offers positive advantages over established disinfection processes. Capital and operating costs are a fraction of those for chlorination, ozone and ultra violet irradiation processes. The complex mixture of disinfecting agents generated has the potential to reach a wider range of micro-organism species and effect a greater removal of pathogens. The capability to remove turbidity and other impurities suggests that a high quality final effluent could be achieved at low expense. The potential benefits to the meat processing industry warrant pilot scale investigations.

7.6.5 Cost

Infrastructure requirements include:

- a contact basin - a concrete tank or an earthen lagoon, of sufficient volume to provide 15 to 45 minutes retention
- electronic equipment
- electrode unit (mounted inside the pipe leading to the contact tank)

Order-of-magnitude costs for a 1 ML/day and a 3 ML/day plant are shown below.

Component	**1 ML/day**	**3 ML/day**
Mechanical & electrical equipment	$2,000	$2,000
Civil engineering work	$5,000	$8,000
Total cost	$7,000	$10,000

7.7 Comparative performance

A wide range of research work has been carried out to date, examining the effectiveness of different disinfection technologies on particular strains of micro-organism. Many of the research reports published are from bench-scale studies using laboratory-grown organisms. Care should be taken when comparing results because they do not always provide a true representation of how a disinfection process will perform in a full-scale system, on organisms that have adapted to a wastewater environment. Figure 7.7 shows the relative performance of some of the main-stream disinfection processes on selected micro-organisms.

Figure 7.7. Relative performance of disinfection technologies
Source: Water Pollution Control Federation, 1986

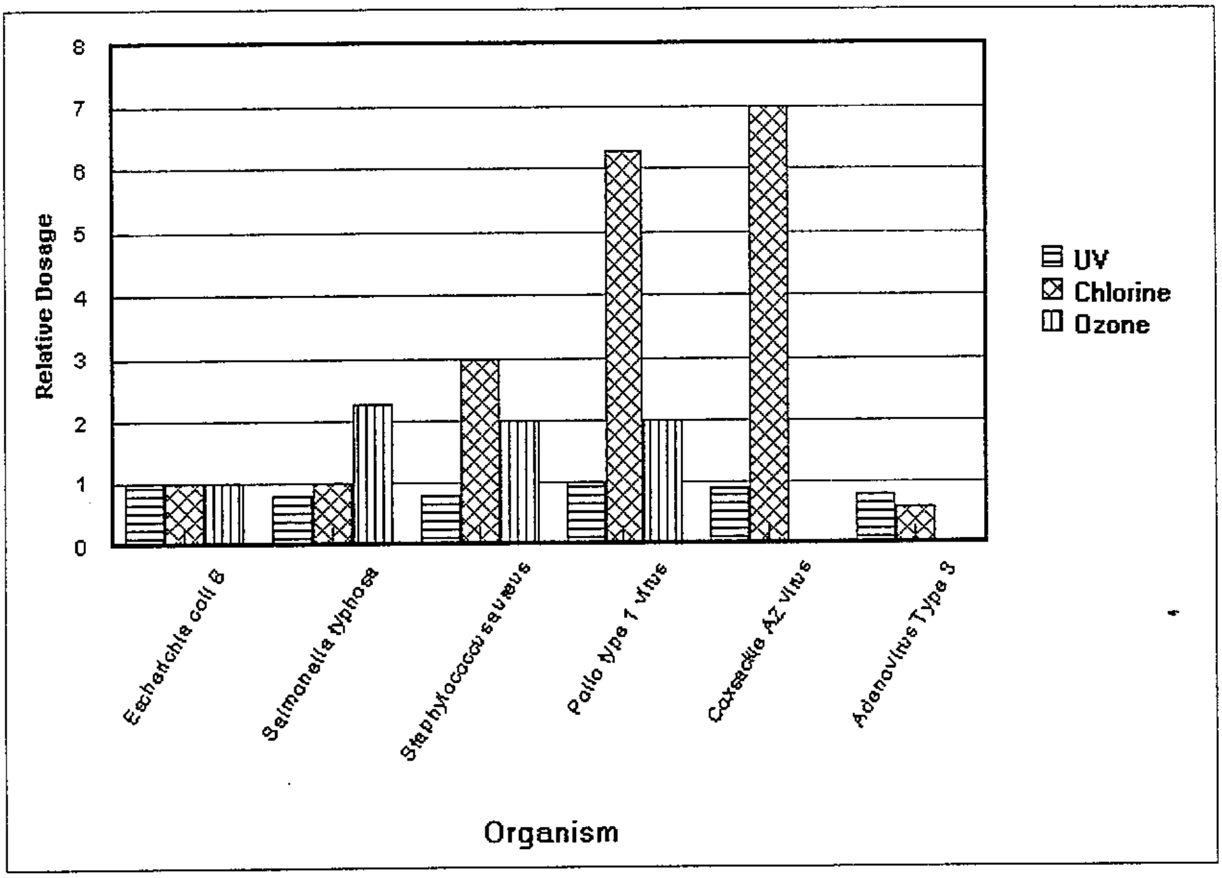


Table 7.7 shows the removal effectiveness of the main-stream disinfection technologies for a range of organisms.

Table 7.7 Effectiveness of main-stream technologies in organism removal

Process	Effective against	Less effective against
Lagoons (20 day retention)	Coliform indicator bacteria Cysts Helminths	
Chlorination	Coliform indicator bacteria Salmonella typhosa Salmonella paratyphi Shigella dysenteriae Stretococcus Staphylococcus Pseudomonas	Mycobacterium tuberculosis more-resistant viruses ova of parasitic worms Amoebic dysentery cysts Giardia cysts Endamoeba histolica cysts
Ozone	Coliform indicator bacteria Poliovirus Protozoa Rotifer Giardia cysts	Helminths
Ultra Violet irradiation	Coliform indicator bacteria Salmonella typhosa Staphylococcus Polio virus Coxsackie virus Adenovirus	Protozoa Helminths Cysts
Membrane (Ultra) Filtration	Bacteria Viruses Protozoa Helminths	

Compiled from: Water Pollution Control federation, 1986 and Metcalf & Eddy, 1991

With chemical and irradiation processes disinfection is achieved by disruption of the organism physiology and this can include:

- damage to the cell wall
- alteration of the cell permeability
- alteration of the protoplasm
- inhibition of enzyme activity

As can be seen from Table 7.7, some organisms are susceptible to this form of disinfection while others are more resistant. In contrast, membrane filtration achieves disinfection through physical separation and hence total removal is possible. With membrane filtration it must be noted that whilst organisms are removed from the effluent, they remain in the concentrate (residue) and this requires disposal through a separate process.

7.8 Discussion

While all of the processes reviewed are capable of achieving the required level of disinfection, several have considerable capital and operating costs, some are only suitable for use with high quality effluents and others have the potential to produce toxic by-products. It should be noted that making comparisons on capital cost alone can be misleading. For a realistic comparison, the Net Present Value (NPV) of capital and operating costs should be determined for the life of the installation. This exercise, however, requires detailed information *specific to a project* and for this reason, such a comparison has not been undertaken.

Of all the technologies considered, membrane filtration has the highest capital cost. This can be attributed to the specialised nature of the various components which include membranes, high pressure feed pumps, backwash pumps, clean-in-place equipment and automatic process control. There are no supply costs for chemical disinfectant since this is a physical separation process. There are, however, supply costs for chemical agents utilised in the cleaning of membranes. Operating costs are also high and the major expenditure is on power for the high pressure feed pumps, chemical cleaning agents and regular maintenance. Pilot scale trials have demonstrated that ultrafiltration could be used on abattoir effluent. This technology could offer other opportunities in addition to disinfection - such as nutrient removal and salinity reduction. If this is found to be feasible, it could offset the high cost if, for example, it eliminated the need to install a nutrient removal process.

Ozone disinfection systems have hight infrastructure requirements - which is to be expected since two additional processes are necessary - one to generate the disinfectant on site and the other to capture and destroy the off-gas. Both of these processes require costly and sophisticated equipment. The aggressive nature of ozone requires all parts that have contact with the gas to be fabricated from costly, high quality materials in order to prevent corrosion. The major operating costs include regular specialised maintenance due to the sophisticated nature of the equipment and the high power requirements for ozone generation and off-gas destruction. The process is effective on secondary effluents, but reduced ozone demands can be achieved with higher quality effluents. The possible formation of toxic by-products is an issue that could preclude the use of ozone.

With UV systems, infrastructure costs are high but the cost of equipment, which includes lamp arrays, electronic ballast and automatic process control, is significantly lower than ozone and microfiltration systems. Operating costs, of which the major components are power and cleaning, are high. In the context of meat processing effluents, with the high levels of suspended solids, grease and fat, there is a high probability of failure.

Chlorination systems have a low infrastructure requirement, particularly if a lagoon can be utilised in lieu of a concrete contact tank. Maintenance and power requirements are also low - the major operating cost being the supply of chlorine. The process is effective on secondary effluents, but reduced chlorine demands can be achieved with higher quality effluents. There is an increasing aversion among regulatory authorities to the use of chlorination when effluent is discharged to an aquatic environment. The reaction of chlorine with the organic and nitrogenous compounds found in meat processing effluents has the potential to form toxic by-products to a much greater extent than with domestic effluent. The levels of toxic compounds produced may well exceed acceptable limits in which case the disinfection of meat processing effluents with chlorine would not be acceptable.

Electrolytic disinfection has obvious attractions - infrastructure requirements are similar to those for chlorination but the major advantage is the extremely low operating cost. It should be noted, however, that the process is un-trialed on meat processing wastewater and the perceived benefits need to be confirmed. The potential savings that this technology could offer the meat processing industry suggest that pilot-scale investigation work is warranted.

In summary, the main features of the various process are presented in Table 7.8.

Table 7.8 . Summary of main features

Comparison criteria	**Membrane filtration**	**Ozone**	**UV**	**Chlorination**	**Electrolytic disinfection**
Capital cost	Very High	Very High	High	Low	Low
Operating cost	Very High	Very High	High	Moderate	Low
Minimum level of treatment	Secondary	Secondary	Secondary	Secondary	Secondary
Environmental acceptance	Good	Good	Good	Regulatory aversion to discharge to aquatic environments	Unknown
Potential formation of toxic by-products	None	Possibility	None	High	Unknown

Footnote:

1. The capital costs provided in this section are order-of-magnitude costs and should not be used for estimation purposes.
2. The relationship between capital cost and size of installation is not linear - doubling the cost for an installation twice the size would be incorrect.

7 CONCLUSIONS

Issues that confront the meat processing industry in terms of effluent disinfection relate mainly to evolving environmental policy. Indications are that the future will see a reduction in effluent discharge to natural waters and a shift to land disposal and re-use schemes. As far as the meat processing industry is concerned, re-use appears to be limited to "external" activities. The use of reclaimed wastewater on the production line is not considered viable due to the risk of contamination and workplace health & safety issues.

All of the mainstream disinfection technologies - chlorination, ozonation, UV irradiation and membrane filtration are capable of achieving the effluent standards. Their main features are summarised as follows:

- Chlorination is the most economic disinfection process but suffers from the disadvantage of toxic by-product formation. This could preclude its use for disinfecting meat processing effluent.

- Ozone is expensive and could also suffer from the disadvantage of toxic by-product formation, but this needs to be confirmed by further research.

- UV irradiation will only operate on high quality effluents and is expected to prove unsuccessful with meat processing wastewaters due to the high levels of suspended solids, grease and fat.

- Membrane filtration requires some form of pre-treatment such as wedge-wire screens **and** DAF flotation. The process has additional benefits which include nutrient removal and salinity reduction - which could off-set the high cost.

- Electrolytic disinfection is an untrialed technology in respect to meat processing wastewaters, but could offer improved disinfection at lower operating costs. The potential benefits need, however, to be confirmed by pilot scale trials.

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