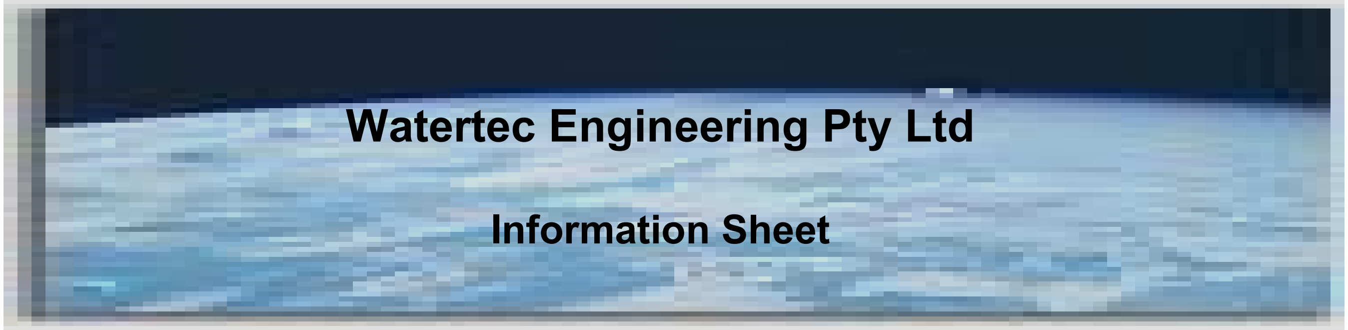

Ozonation of

Municipal Wastewater

OZGEN OZONATORS
BY

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INTRODUCTION

Disinfection of municipal wastewater with ozone is by no means a new technology, as a large number of sewage treatment plants throughout the world successfully use this treatment method. Over many years of practical operation, ozone has proved to be a very effective and reliable disinfectant for sewage. Whilst it is fair to say that several of the ozone facilities installed for wastewater disinfection in the 1970's experienced many operational difficulties, recent advances in ozone generating equipment together with improved installation and applications knowledge makes this treatment technology a viable alternative.

With high quality ozone generating equipment now being manufactured in Australia, ozone is economically viable for wastewater disinfection, particularly with plants up to 30,000 EP. Ozone offers several technical advantages over other disinfection technologies, such as chlorine, chlorine dioxide (ClO_2), or ultra-violet irradiation (UV).

Considering the environmental concerns when municipal wastewater is discharged into natural receiving waterways, ozone should be seriously considered, as it is the most environmental acceptable oxidising disinfectant commercially available today.

The following information is presented in a question and answer format as the questions dealt with have commonly been asked when we have been requested to provide relevant information to enable this new technology to be fairly compared to more traditional disinfection methods.

Question 1.

Has ozone been successfully used for wastewater disinfection in Australia and overseas?

Ozone has been successfully applied to many wastewater plants since the early 1970's, with most installations being in Europe and the USA.

Although many operational problems existed with the first generation of installations, when ozone has been applied correctly, the required disinfection criteria have been met. These early problems were primarily caused by the lack of knowledge, or experience, with this type of ozonation facility. From the experiences gained with the practical application of ozone in the 1970's, ozonation facilities in wastewater over the past ten years has developed to the stage where both economical and technically viable disinfection systems have been provided with many wastewater plants.

When compared to Europe and the USA, ozonation in Australia is a relatively new industry; therefore, there are very few installations where ozone is used for sewage disinfection. As at 1996, there were only a few very small ozone disinfection systems operating. The availability of ozone generating equipment and process applications knowledge has developed significantly over the past few years, to the point where it is now viable as an alternative disinfectant for wastewater treatment in Australia.

Question 2.

How effective is ozone for wastewater disinfection when compared to other technologies, such as chlorine or UV?

There is now more than sufficient scientific documentation and experience to show that ozone is the most effective commercially available disinfectant for wastewater. Ozone is effective against all micro-organisms which are of concern in wastewater and can be applied to provide the desired level of disinfection. Also, ozone provides several other benefits to wastewater quality, which is not achievable with other technologies.

In contrast, chlorine is not very effective for some organisms, such as Giardia and Cryptosporidium, but more importantly produces chlorinated organic by-products, which are known to be detrimental to receiving waterways. Ultra violet irradiation, when applied correctly, provides very effective disinfection, however there are a number of deficiencies in this process, such as fouling of UV tubes, the effectiveness decreases rapidly and suspended solids increase and photoreactivation of organisms after disinfection.

Ozone is able to provide any level of disinfection, with any quality of wastewater effluent, the limiting factor of course being economics. There has never been a question as to the environmental acceptability and effectiveness of ozone as an alternative disinfectant for wastewater.

Question 3.

What specific treatment benefits does ozone provide, over other technologies?

Being the most powerfully commercial available oxidant, ozone offers several important benefits over other disinfection techniques, such as chlorine, chlorine dioxide, UV and membrane technology.

The main treatment benefits of ozone include:

- Ozone is very effective for killing bacteria, bacteriophages, cysts and viruses.
- Short contact times are required, when compared to chlorine. Contact times of 2-10 minutes have proven to be effective for disinfection of wastewater.
- Disinfection efficiency is not greatly affected by pH and temperature variations.
- Ozone increases dissolved oxygen level of the treated effluent, which is beneficial to the receiving waterways.
- No toxicity to aquatic life has been observed in the many studies undertaken on ozone disinfected effluents.
- No increase in TDS occurs in ozonated wastewater.
- Ozone does not produce triahalomethanes (THM’s)
- Due to the instability of ozone, residuals will not persist. Therefore removals of residuals are not necessary.
- Colour and odour being removed during ozonation generally improve the wastewater quality.

- Using ozone residual monitoring equipment the ozone dose may be automated to ensure that adequate disinfection is always being achieved.
- Ozone reduces the COD of the final effluent.

Considering these comments, one can see that ozone overcomes many of the concerns and difficulties associated with other disinfection technologies.

Question 4.

Is ozone cost competitive with other wastewater disinfection technologies?

Chlorine has always been the most economical disinfection method for wastewater, however the environmental concerns of chlorination are forcing alternatives, although more expensive, disinfection technologies to be implemented. Of the viable alternatives, UV disinfection has been generally accepted to be the most cost effective option.

Although the effectiveness of ozone has never been in doubt, the capital cost has been sufficiently high to cast doubt on its viability. With recent advances in ozone generating equipment and applications technology, ozonation is now cost competitive with UV irradiation. This is particularly the case with smaller sewage wastewater treatment plants, typically up to 30,000EP.

Several studies have been undertaken over the past few years comparing ozone, UV, chlorine dioxide and membrane filtration as alternatives to normal chlorination. On a nett present worth basis ozone, UV and ClO_2 have shown to be viable alternatives, the most cost effective order of which appears to vary according to the effluent quality and author.

Question 5.

Why is ozone now price competitive?

Until recently, all but very small ozone generators had to be sourced from overseas. Watertec Engineering Pty Ltd now manufactures the Ozgen range of ozone generating and associated equipment in Australia. Ozonators with capacities of up to 3kg/h are incorporated in this range, making them suitable for wastewater plants of up to 30,000 EP. The actual wastewater plant size that will be accommodated with this equipment range will of course depend on the hydraulic characteristics and effluent quality.

This Australian made equipment has substantially reduced the cost of installing an ozone facility, to the point where the installed capital cost is comparable to current UV technology. With larger wastewater plants an ozonation system will have a higher capital cost than UV, due to the equipment being imported, however with recent advances in generating equipment ozone is still a viable option.

Considering the above comments, ozone now offers several technical advantages over other disinfection technologies, without the previously expected high cost penalty.

Question 6.

Can ozone be used for any wastewater treatment plant?

Ozone is a very reactive oxidant, therefore the dose rate required to achieve disinfection is dependent on the effluent quality. Although ozone is technically able to treat any effluent quality, the dose rate that is needed for some poor quality effluents may preclude its use on economic grounds.

The quality of effluent will depend on the treatment process and the source of the wastewater. For example, wastewater which is largely produced from industries such as wool scouring and tanneries will most likely have a high colour, suspended solids, BOD, COD, etc, resulting in a high ozone demand. A normal domestic effluent may have an ozone requirement of 3-5mg/l, whereby an industrialised effluent may have an ozone demand of 30mg/l.

On this basis, ozone is very suitable for wastewater disinfection where the influent is primarily derived from domestic sources. This of course does not preclude ozone's use in wastewater from industrial sources; however, in such cases the suitability of ozone must be assessed.

As described earlier, ozone will do more than simply disinfect the effluent, therefore this should not always be the only criteria used to determine ozone suitability. Other criteria may be removal of colour, odour, increase dissolved oxygen etc.

Question 7.

Is a pilot plant study necessary to establish the required ozone dose?

Considering that there are many sewage treatment processes and influent qualities, the exact plant effluent make up may well be differed from substantially identical treatment plants. There are many factors, which will affect the actual ozone demand and treatment design to ensure satisfactory disinfection. Therefore, no ozone disinfection facility should be implemented without undertaking some physical testing of the particular effluent in question. Although we can make an educated estimate on the ozone requirement based on effluent analyses, we generally cannot afford the luxury of substantially oversizing the ozonation facility to accommodate uncertainties in the ozone dose requirements.

For a typical domestic wastewater, which achieves a high quality effluent after the treatment process, simple ozone demand testing should be quite sufficient to have confidence in sizing the treatment equipment. On the other hand, if the ozone demand is found to be higher than 5mg/l, or the effluent has a high colour, suspended solids, BOD etc, then demand testing should be done to initially establish the economic viability of using ozone, followed by pilot plant testing.

Testing for the ozone demand of a wastewater effluent is quite simple and not costly to undertake. For an effluent, which indicates a high ozone demand, pilot plant testing is a necessary step, as the overall diffusion/contact system should be duplicated as closely as possible to a full scale plant.
The pilot plant should be as large as is feasible to minimise the possibility of errors in scale up to a full plant facility. During pilot plant testing various treatment parameters may be evaluated, such as using air or oxygen as the feed gas, contact times, ozone concentration etc.

Providing the effluent quality is typical for the plant being evaluated, the results of ozone demand testing may be obtained within one day. Additional time would of course be required for microbiological analyses. Typical pilot plant testing would require the facility to be operational for between 1 and 4 weeks.

Question 8.

Can an ozone disinfection system be retrofitted to an existing wastewater treatment plant?

Considering that ozone is applied to the final plant effluent, it can normally be retrofitted without interfering with the plant or treatment process. There are factors that must be considered when establishing the suitability of retrofitting an ozonation system, such as the hydraulic conditions available for the final effluent, flow variations, the degree of intermittent operation, effluent quality, available space, availability of services, etc.

Where chlorine is presently used for disinfection, the chlorine contactor can often be modified to accommodate ozone.

Question 9.

Will ozone reduce the effluent BOD?

During ozonation of wastewater, ozone will partially oxidise many organic contaminants. With some wastewaters, ozone will have little effect on BOD_5, although with adequate ozonation BOD_5 reductions have been observed with many installations.

Question 10.

Will ozone treatment lower the ammonia residual in the treated effluent?

Ozone has a very slow reaction with nitrogen based compounds; therefore within the treatment conditions of wastewater disinfection ozone will not have any affect on ammonia levels. If ammonia is a problem then it must be treated by more traditional methods.

Question 11.

Will ozone treatment lower the phosphorous residual in the treated effluent?

Ozone does not react with phosphorous; therefore traditional physio-chemical processes must remove this contaminant.

Question 12.

Does ozone increase the toxicity of receiving waterways?

Although ozone primarily reverts to oxygen, oxidation reactions produce ozonated by-products. Molecular ozone and free radical pathways, resulting from the complex decomposition of ozone, play a role in the formation of by-products in ozonated wastewater. The nature of organic matter, which serves as a precursor material for ozone by-products, varies considerably.

Under practical conditions in wastewater disinfection little organic material is fully mineralised. Most organic material is partially oxidised. Some ozonated by-products, which may occur, include aldehydes, carboxylic acids, keytones, and alkanes.

During disinfection of wastewater ozone does not produce THM's, although under practical application nor will it oxidise THM's, which have been produced by previous chlorination.

Many studies have been undertaken to evaluate the toxic effect of ozonated wastewater on receiving waterways. All studies undertaken have shown that the by-products of ozonation do not increase the toxicity of receiving waterways and in fact have generally shown a beneficial effect in that the DO is substantially increased after ozonation.

Question 13.

What ozone dose rate will be needed?

As discussed earlier, the ozone demand and therefore dose required will vary considerably depending on the effluent quality and wastewater source. The ozone dose requirement could vary between 2 and 30+ mg/l.

Although demand or pilot plant testing is the only guaranteed way of determining the ozone dose needed, the following details may be used as a guide. This information is compiled from practical experience gained with various wastewater treatment plants throughout the world.

Ozone should generally be considered as a polishing treatment; otherwise it is not likely to be considered economically viable. For a small treatment plant ozone may be used after physical treatment rather than biological, even though the dose rate will be quite high. With such a plant, the benefits obtained from an ozone treatment may outweigh the increased cost.

Effluent Quality	**Absorbed O_3 Dose for 200 CFU/100ml (mg/l O_3)**	**Absorbed O_3 Dose for <10 CFU/100ml (mg/l O_3)**
Nitrified/Clarified	3 - 5	10-20
Secondary/Clarified	5 - 10	15-25
Clarified/Filtered	20-30	40-50

Note: These ozone dose rates are a guide only and do not take into account additional ozone demands associated with some industrial effluents.

As can be seen from the above table the ozone dose needed can vary considerably, however, for the great majority of municipal wastewater treatment plants, an ozone dose rate of 5mg/l will provide satisfactory disinfection.

Question 14.

How do I determine the ozonator capacity?

Being an oxidation process, the required quantity, or weight, of ozone that must be dosed varies on a proportional basis to the instantaneous effluent flow. Therefore, the ozonator must be sized to accommodate the required dose rate (mg/l) of ozone to the instantaneous peak dry weather flow (IPDWF).

From these comments it is obvious that an accurate assessment of the IPDWF is essential. If this flow rate is underestimated then the ozonator may not have sufficient capacity to meet disinfectant criteria during the peak dry weather flow (PDWF) periods. Likewise, if the IPDWF is over estimated, the capital cost for equipment will be unnecessarily high.

The treatment plant hydraulics therefore plays an important role in optimising an ozone disinfection system. For example, the better the flow rate is averaged throughout the day, the smaller the ozone generator will need to be. On the other hand, for treatment plants, which use an intermittent decanting system with little or no storage or balancing, the ozonator must be sized to accommodate the maximum flow during the decanting process.

The following example will detail our recommended method for sizing the ozonation equipment.

Ozonator Sizing Example

Plant	-	Municipal Wastewater
Wastewater Source	-	Primarily Domestic Sewage
Plant Capacity	-	15,000 EP
Average Dry Weather Flow	-	3.6ML/d
Peak Dry Weather Flow	-	7.2ML/d
Maximum Instantaneous Flow	-	139 l/sec
BOD_5	-	<10mg/l

Suspended Solids	-	<15mg/l
Required Disinfection	-	<200CFU/100ml

For this quality effluent an ozone dose of 5mg/l should be quite adequate, when applied to the peak instantaneous flow. On this basis the ozonator would be able to dose far in excess of 5mg/l for the majority of the plant operating time. This of course depends on the degree of ponding and therefore flow variations.

The ozone dose may then be calculated by the following formula.

$$kg/h\ O_3 = \frac{mg/l\ O_3 \times Flow\ (L/h)}{1,000,000}$$

$$\frac{5 \times 139 \times 3600}{1,000,000} = 2.5kg/h\ ozone$$

For this example we would size the ozone generator/s to have a maximum output of 2.5kg/h. However, if an ozonator with a slightly higher output may be provided, at minimal or no extra cost then this would be selected.

Question 15.

What Ozonator Type should I select?

The oxidation and disinfection criteria required for municipal wastewater dictates that the ozone can **only** be produced by the corona discharge principal. Other ozone generation principles, such as ultra violet irradiation at 194 nanometres, are not capable of producing ozone at sufficient concentrations to perform the required task.

Of the commercially available corona discharge ozone generators, experience over the past two decades has clearly shown that traditional equipment using the low and medium frequency generation principal should only be considered. Equipment that has proved to be troublesome in the past include high frequency ozone generators, air cooled generators and systems which use a double cooling system on the generation cell or dielectric system.

With recent advances in power electronics, medium frequency ozone generators have become far more efficient, reliable and economical. There are many technical benefits in operating an ozonator at medium frequency (60 -600Hz), providing the generation cell current densities are not too high.

Using modern power electronics, medium frequency technology allows great flexibility in automating and varying the generation criteria to suit the specific application needs. Also, for a given output of ozone the generation module for a medium frequency ozonator will be considerably smaller than for a low frequency generator. This lowers both the capital and maintenance costs for the equipment.

Question 16.

Should I use Air or Oxygen as the Ozonator Feed Gas?

From a technical, or treatment, aspect, the main difference between using air or oxygen as the feed gas is the concentration of ozone that will be dosed to the wastewater. Typical ozone concentrations that are produced by commercial ozonators are 1.5 - 3% w/w O_3 for air and 4-10% w/w O_3 for oxygen.

There are several factors which determine whether air or oxygen should be used, some of the most important ones being;

- The primary purpose for the ozone treatment (eg oxidation or disinfection)
- Contactor design
- Type of ozone injection/diffusion system.
- Effluent flow variations.

Where oxidation of water contaminants, such as colour or dissolved organics is of primary concern, an ozone concentration of at least 5% w/w would be more appropriate. However, should disinfection be the primary concern then a lower ozone concentration would be more beneficial.

Air fed ozone generators operate most efficiently when producing ozone at concentrations of between 1.5 and 2% w/w. For disinfection, the main advantage of using lower ozone concentrations is that the residual can be more easily maintained within the contact system.

When air is used with low ozone concentrations, the ratio of the gas volume to sewage flow is far higher than for oxygen, where higher ozone concentrations are used.

For example, for a 1kg/h ozonator operating on air at 2% w/w O_3, the air flow rate will be 43m^3/h. For the same ozonator operating on oxygen at 6% w/w O_3 the oxygen flow rate will be 12.5m^3/h. This variation in gas flow rate is very important when designing the contactor hydraulics and ozone injection/diffusion system. With a traditional fine bubble diffusion system in a multipass, baffled contact chamber, the ratio of gas to effluent flow must be kept within a specific range, otherwise significant short-circuiting occurs in the contact chamber compartments.

The following comments may be used as a general guide.

Air Fed Ozonator

For small treatment plants, which will require an ozone dose of up to 1.5kg/h, air feed will be the most cost appropriate option, when considering capital, running and maintenance cost. The only factors, which will influence this, are the dose rate of ozone that will be required (mg/l O_3) and whether higher ozone concentrations are necessary.

As a guide, if an ozone dose of >5mg/l is necessary then air should not be used in a traditional baffled contact chamber using fine bubble diffusers. In such a system the gas to liquid flow ratio should not exceed $0.2m^3/h$ of air to $1m^3/h$ of effluent flow. A greater ratio may be accommodated; however a different contact chamber design is necessary.

As a comment on air preparation systems, the majority of failures that have occurred with air fed ozone generation systems are inadequate air preparation. It is of paramount importance that the air is filtered and reliably dried to at least -60°C pressure dew point. To achieve this, a pressure air preparation system, using effective refrigerated coolers and pressure swing dryers, should be used. Ozone generators which utilise the vacuum produced by the injection system to draw air through heat regenerated desiccant dryers, is not a reliable and satisfactory method of air treatment for industrial applications.

Oxygen Fed Ozonators

Oxygen may be used as the feed gas in virtually all applications; however the main limiting factor is the capital, in the case of oxygen generating equipment, or the operating costs when using liquid oxygen. (LOX).

Oxygen may be provided by bulk liquid supply or from a pressure swing absorption oxygen generation system. The latter method uses a zeolite media, which separates the nitrogen and concentrates the oxygen from pressurised air. PSA oxygen generators are now commonly used in small and large ozone generation systems throughout the world. Although this equipment is expensive, it is often the best choice when evaluating a system on a present worth basis.

Considering that oxygen is technically suitable for virtually all applications, its use should be considered and costed for both capital and operating costs for most wastewater disinfection applications. An oxygen fed ozonator would almost certainly be required should the ozone dose exceed 20mg/l.

When using oxygen, the ozone contactor design is more critical than for an air fed system, as diffusing a high percentage of the ozone into the effluent becomes more difficult as the ozone concentration increases.

Question 17.

What Ozone Contact Time is required?

Depending on the ozone injection and contactor design, a contact time of between 5 and 15 minutes is normally required for wastewater disinfection.

Inactivation of bacteria and most micro-biological contaminants occurs within 1 to 2 minutes. However, to ensure inactivation of more persistent organisms, such as viruses and cysts, an effective contact time of at least 5 minutes is recommended.

As a minimum requirement it is recommended that the ozone contactor be designed on a hydraulic retention time of 10 minutes at the instantaneous peak dry weather flow.

The most important factor is to design the contact system so that the ozone demand is initially met then a residual maintained for the required contact time, to ensure disinfection. The system designer will need to ensure that the correct CT (contact time: residual ratio) is achieved, 6.0mg/l/min being normal.

Question 18.

What type of Ozone Injection System is best suited for my Plant?

Although there are many types of ozone injection and diffusion systems for small to medium wastewater treatment plants, there are only two cost effective and viable options.

- Fine Bubble Diffusers
- Sidestream Vacuum Injectors

Fine Bubble Diffusers

This ozone injection method involves installing a grid of ceramic diffusers on the floor of one or more compartments of the ozone contact tank. These diffusers normally provide bubbles in the size range of 1-2mm and must be positioned with a minimum of 5 metres of water above the diffuser.

The main advantage of these diffusers is that no additional energy, apart from feed gas preparation, is necessary. The technology is well proven and used in many water and wastewater treatment plants throughout the world. Under practical applications, diffusion efficiencies of approximately 90% are achieved with well designed systems.

The main disadvantages associated with fine bubble diffusers in wastewater is that the diffuser pores often clog with precipitated metal salts and other fine contaminants during periods when ozone injection is not required. Also, careful design of the contactor and overall hydraulics is very necessary to ensure adequate mixing with the wastewater flow is achieved and that the correct gas to water ratio is maintained.

As a guide, ceramic diffusers would generally be selected for plant installations where the ozone dose rate exceeds 3kg/h and where traditional baffled multipass-chamber contact tanks are used.

Vacuum Injectors

Of these two options, vacuum injectors are the most efficient means of ozone diffusion, however they consume additional energy.

These injectors involve pumping final treated effluent to the injector, at a flow rate that is directly proportional to the ozone/gas mixture. This pump supplies water at an elevated pressure to the ozone injector, which draws the ozone/gas mixture from the ozonator under sub-atmospheric pressure. These injectors are very efficient at producing very small bubble sizes, resulting in high diffusion efficiencies. A well designed system will achieve diffusion efficiencies of up to 95%.

The fine bubbles and bypass water flow produced by these injectors is then distributed into one or more compartments of the ozone contact tank. Depending on the particular plant design, multiple vacuum injectors may be used to introduce ozone to different contact chamber compartments.

The main advantages of this injection technique are that the ozone generator and all pipework containing ozone gas operate at sub-atmospheric pressure and that high ozone diffusion efficiencies are achievable.

Operating an ozonator under sub-atmospheric pressure provides the safest possible method of operating a system.

The main disadvantage with using injectors is that additional pumping is required, which increases the operating costs, although not significantly.

Experience in both Australia and overseas has shown that this injection technology is very suitable for small applications with ozone injection rates of up to 3kg/h. Although larger systems could use injector technology, economics would favour the use of fine bubble diffusers.

Question 19.

What Type of Ozone Contactor should be selected?

The contactor design will largely depend on the site layout and hydraulic head available in the wastewater treatment plant. Where the wastewater is pumped to the ozone disinfection system at a constant rate, there are several contactor designs that may be used. These include vortex contact tanks, baffled pressure contact tanks and traditional concrete multipass contactors.

Most wastewater plants operate on a gravity discharge from the balance ponds, therefore an ozone disinfection system should ideally be able to accommodate this limited available head. In these cases, the two viable options include;

- Multiple fibreglass tanks with internal diffusion zones
- Concrete multipass contactors

Multiple Contact Tanks

Considering that for disinfection ozone must be introduced into at least two separate contact compartments, two or three contact tanks would need to be installed in series. These contactors would typically be constructed in fibreglass and buried to accommodate gravity flow. Each contactor would incorporate an ozone gas distribution system to ensure that short circuiting is minimised.

This style of ozone contact system is most suitable for small plants, with instantaneous effluent flows of up to 100 l/sec.

Concrete Contactors

This is a more traditional type of ozone contactor, as commonly used in water treatment plants throughout the world. These contactors are designed as a multipass system with the ozone/gas mixture rising counterflow to the wastewater flow. When designed correctly these contactors provide effective and trouble free use of ozone.

Although these contactors are simple in principal, they must be designed correctly to suit the plant hydraulics and quantity of ozone/gas to be injected. Many disappointing results have been experienced throughout the world due to poor understanding or design. Although this type of contactor may be used with any sized plant, it is most suitable for plants with instantaneous effluent flows of > 100 l/sec.

Question 20.

How is the Ozone remaining in the Contactor Off-Gas destroyed?

When an ozone disinfection system for wastewater is designed correctly, there will always be some ozone remaining in the air or oxygen off-gas from the ozone contactor. The amount of ozone remaining in the off-gas will vary from between 0.05 and 0.6% w/w, depending on the ozone concentration and diffusion/contactor design. Considering that ozone is a toxic gas and the maximum suggested human exposure limit is 0.1ppm in the air, any remaining ozone in the off-gas must be destroyed before being discharged to atmosphere.

Three methods are commonly used for ozone destruction.

- Reaction with granular activated carbon
- Thermal destructors
- Thermal/catalytic destructors

Activated Carbon Destructors

When ozone gas is passed through a bed of granular activated carbon ozone is destroyed by oxidation of the carbon in a slow rate combustion reaction. The carbon is slowly broken up or powderised and heat is generated in the combustion process. Therefore, this type of destructor should **not** be used with an oxygen fed ozone system.

For wastewater treatment plants, activated carbon off-gas destructors should not be used. The only exception may be for very small plants with ozone generator capacities of up to 200g/h.

Thermal Destructors

As the name implies a thermal destructor heats the off-gas to a point where ozone is destroyed. Ozone destruction occurs rapidly as the gas temperature is elevated. At 350°C, all of the ozone is thermally reduced to oxygen within a very short contact time.

In a wastewater treatment plant, the ozone contactors would be designed with airtight compartments and the off-gas fed to a basic water/mist eliminator then to an electrically heated thermal destructor. These destructors are designed so that the exit temperature is controlled at 350C.

Thermal destructors have two main disadvantages being that they require electrical energy to heat the off-gas to 350°C and that there is the potential to cause an oxygen fire should foam carryover occur into the destruction unit, although this is only possible when oxygen is used as the feed gas.

When designed correctly thermal destructors will provide efficient and reliable ozone off-gas destruction.

Thermal/Catalytic Destructors

Although these types of destructors have been available for several years, they are the newest of the technologies. With these systems a metal catalyst, normally palladium or manganese dioxide acts as a catalyst to convert the ozone to oxygen. These destructors are very efficient and will reliably control ozone discharge levels to within the required safety limits. As with the thermal destructors the off-gas is taken from the contact chamber, passed through a water/mist eliminator then fed to the catalytic destructor. The off-gas is then heated to approximately 60°C, to ensure that condensation does not occur on the catalyst bed. This heated gas then passes through a bed of catalyst where the ozone is destroyed. A ventilation fan is usually provided on the discharge of the destructor, which alleviates the necessity to have the ozone contact tank fully air tight.

For wastewater treatment plants, the thermal/catalytic ozone destructors are the most suitable technology as they have a low power requirement, are safe in operation and are safe to be used with either air or oxygen fed systems.

Question 21.

Will foaming occur in the Ozone Contactor?

Most sewage effluents have a tendency to foam. The process of ozone diffusion, which is primarily a dissolved air flotation system, together with the oxidation properties of the ozone will most likely produce some scum and foaming in the ozone contactor. Without some form of foam control this may cause problems by carry over into the off-gas destruction system.

A simple spray system installed in the head space of the ozone contactor has proved to be effective in preventing foam related problems.

Question 22.

Can an Ozone Disinfection System be fully automated?

The main criteria for disinfection of sewage with ozone is that an adequate residual is maintained for the required contact time. To ensure that this occurs, there are three primary monitoring and automation systems commonly used.

- Flow Pacing.
- Ozone Residual Control.
- Ozone Off-gas Control.

Flow Pacing

With ozonators that operate on medium frequency technology, the ozone output is directly proportional to the frequency applied to the generation cells. Therefore, automating the ozonator is very simple, particularly with reference to flow pacing. The first requirement for automation is that if the effluent flow varies through the contactor then the ozonator output must be automatically regulated to dose on a proportional basis to the flow rate. In these cases a flow meter is required for the wastewater feed to the ozone contactor, which will give a 4-20mA signal to the ozonator for automation. The ozone dose would then be regulated proportionally to the effluent flow.

Ozone Residual Control

The next stage of automation is to ensure that an adequate residual of ozone is maintained in the contactor. One method for achieving this is by measuring the amount of ozone residual in the contactor using dissolved ozone monitoring equipment.

Recent advances in residual ozone monitors now allow this technology to be effectively used for wastewater applications. The treated water in the final contact chamber would be monitored for dissolved ozone, then the ozonator automatically regulated to maintain the desired or preset ozone residual. The typical ozone residual at the end of the contact period would be 0.1mg/l. This automation technique would normally be used in conjunction with flow pacing.

Ozone Off-gas Control

Another automation method that has effectively been used in wastewater treatment plants is to monitor the ozone concentration in the off-gas, using a specially designed spectrophotometer instrument. As the ozone demand increases, the diffusion efficiency increases, resulting in a lower ozone concentration in the off-gas. With this automation technique the ozonator output is automatically increased to maintain a pre-set off-gas ozone concentration. This has shown to maintain an acceptable ozone residual in the final effluent, and therefore ensure disinfection.

Depending on the plant design and requirements to ensure optimum disinfection, any or a combination of all three automation methods may be used.

Where the gas effluent flow ratio is critical, or oxygen is used as the feed gas, an alternative method of controlling the ozone dose is to maintain a set ozone concentration in the feed gas and vary the actual quantity, or flow rate, of ozone/oxygen being fed to the injection system. This automation method will optimise the treatment process and provide the lowest possible operating cost.

Question 23.

Can an Ozone Disinfection System work with large flow variations and intermittent operation?

The current technology of ozone generators provides a high turndown capability, therefore when a flow meter is installed, large effluent flow variations may be accommodated. However, in practical terms a turndown of 10:1 would be the maximum considered viable. ***Ozgen*** ozonators may be operated with higher turndown ratios; however this would rarely be required with most wastewater applications. If the plant flow reduced below 10% then we would normally allow the ozonator to provide a higher than required dose rate.

When designed correctly an ozone disinfection facility may be operated intermittently and frequently stopped. Unless the ozonator has been isolated for several hours, adequate dosing would recommence as soon as the equipment is restarted.

Question 24.

Ozone is a Toxic Gas. How safe is it in a wastewater treatment plant with limited operator attendance?

When an ozone treatment facility is designed and installed correctly it is inherently safe and poses little danger to plant operators or the local environment, particularly when the ozone is added to the effluent via a vacuum injector. With the ozonator and pipework operating at sub-atmospheric pressure, any pipe or equipment failures will simply allow atmospheric air to be drawn into the ozonator, which will automatically stop via its flow monitoring system. Even when ozone is generated and injected under pressure, it is produced at relatively low concentrations and is not stored under high pressure, as is gas chlorine.

Although the systems are designed to be inherently safe, all pipework carrying ozone gas should be constructed using 316L stainless steel. As an additional safety measure an ozone gas leak detector should be installed in the ozonator room and anywhere there is a possibility of ozone gas leaking into the atmosphere. These leak detectors are designed to provide a warning at 0.1ppm of ozone in air, which is the TLV, then alarm and shut down the ozonator at 0.3ppm.

The ozonation system must be designed so that the entire system operates in a fail-safe manner, whereby any fault scenario will isolate the relevant equipment to ensure personnel safety and not damage equipment.

There are many ozone installations in Australia and overseas which are designed to operate with minimal operator attendance. Although many installations have not been done correctly throughout the world, there has never been a recorded death that is directly related to ozone gas.

Question 25.

What operator involvement is needed to run an ozone disinfection facility?

The daily requirements for plant operators will vary according to the size of the installation, the feed gas type and the ozone injection system. However, the daily requirements for operators are minimal and generally related to visual checking of the equipment.

Although daily checking of the ozonation facility is not necessarily required, when the operators are on site they should observe all operating parameters of the ozonator and its associated equipment and log specific parameters. These include items such as ozone output, gas flow rates, cooling water flow rates, air pressures etc.

Routine checking of the ozonator facility should not require more than 10-15 minutes of an operators time.

Question 26.

What are the typical capital costs for an ozone disinfection facility?

Capital Costs

The capital costs for a specific wastewater treatment plant will obviously depend on the ozone dose rate required to achieve satisfactory disinfection. As detailed earlier, the ozone dose rate may vary considerably, depending on the effluent source and quality of the effluent prior to disinfection. However, the following budget prices may be used as a guide for a normal wastewater treatment plant, which is primarily derived from a domestic sewage source and provides a good quality secondary effluent.

Operating Costs

The operating costs for an ozone facility are directly related to the quantity of ozone dosed. Although the ozone equipment is sized to provide the required dose rate to the maximum instantaneous flow, the actual daily consumption of ozone will relate to the average dry weather flow, over a 24-hour period. Also, the demand, or ozone requirement, will vary both daily and seasonally. Considering these factors, the estimated operating costs given for an ozonation facility should be quite conservative.

With an air fed or PSA oxygen ozone facility, the direct operating costs are associated with the power actually consumed.

Where liquid oxygen is used as the feed gas then the operating costs will be a combination of the power consumed and the oxygen used. Although the power consumption is significantly reduced when oxygen is used as the feed gas, the cost of liquid oxygen usually far outweighs the power savings. Also, the cost of liquid oxygen will depend on the location and availability of a refilling service.

The stated budget operating costs have been determined using the following design criteria.

Power for Ozone Generation	-	18kwh/kg (With air feed)
	-	7.5kwh/kg (With oxygen feed)
Air Preparation	-	7kwh/kg
Off-Gas Destruction	-	2kwh/kg
Vacuum Ozone Injection	-	4kwh/kg
PSA Oxygen	-	750kwh/tonne
Liquid Oxygen	-	0.4 0$/m^3

Note: Liquid oxygen costs are a rough guide only, as this will depend on the quantity and locality of the installation.

Maintenance Costs

The direct maintenance costs for the ozonation facility will depend on the feed gas and any duty standby equipment used. Routine maintenance of the ozone generator involves dismantling and cleaning the ozone generation cells on a two yearly basis and servicing minor pneumatic and hydraulic components. With an air fed system regular servicing is required for the air compressor and associated filtration systems. The only other maintenance required involves servicing of the ozone off-gas leak detection equipment, ozone residual analysers and calibration checks of the automation systems.

The following table details typical costs (A$) associated with an ozone disinfection facility for wastewater plants of up to 30,000EP.

Plant Capacity (EP)	ADWF (ML/d)	Max. Flow Rate (l/sec)	Ozone Dose (mg/l)	Ozonator Size (kg/h O_3)	Feed Gas	Approx. Capital Cost $	Annual Operating Cost $	Annual Maintenance Cost $
5000	1.2	41	5	0.75	Air	185,000	12,000	7,000
10,000	2.4	82	5	1.5	Air	250,000	18,000	9,000
10,000	2.4	82	5	1.5	Oxygen	170,000	32,000	6,000
15,000	3.6	123	5	2.25	Oxygen	300,000	65,000	7,000
15,000	3.6	123	5	2.25	PSA / Oxygen	450,000	22,000	12,000
20,000	4.8	166	5	3.0	Oxygen	350,000	86,000	7,500
20,000	4.8	166	5	3.0	PSA /	495,000	30,000	12,500

					Oxygen			
25,000	6.0	208	5	3.75	Oxygen	590,000	96,000	10,000
25,000	6.0	208	5	3.75	PSA / Oxygen	990,000	26,000	17,000
30,000	7.2	250	5	4.5	Oxygen	690,000	115,000	18,000
30,000	7.2	250	5	4.5	PSA / Oxygen	1,100,000	32,000	25,000

Note: The capital costs stated include supply, installation, commissioning and operator training of the entire ozone treatment facility. This includes the ozone contactor. The only capital items that have not been included is the provision of a room, or building, to house the ozonation equipment.

Although approximate plant capacities have been given in the above table, it should be noted that the most important design consideration is the maximum instantaneous flow rate. The ozonator size and therefore capital cost is based on the ozone dose, which is applied to this flow rate.

CONCLUSION

The above information clearly shows that although ozonation of wastewater is fundamentally simple and is well proven throughout the world, practical assessment of the requirements for ozone and its practical application are not. There are many aspects to consider, to enable designers to fairly and accurately assess the suitability of ozone as an alternative disinfectant for wastewater.

There is now enough history and information available to prove that ozone is a very effective and viable alternative wastewater disinfectant, particularly since the introduction of the ***Ozgen*** Australian made ozone generators. Also, the specialist knowledge and experience necessary for correctly assessing the suitability of ozone for wastewater applications is available in Australia.

Ozone is now a viable alternative disinfectant to presently favoured technologies, such as UV, however when applied correctly ozone will provide significantly additional benefits to the water quality, with little or no cost penalty.

Watertec Engineering Pty. Ltd. is specialists in the field of industrial and municipal water treatment. Having completely designed and established a manufacturing facility for ozone generators and associated equipment in Australia, *Watertec Engineering* has an intimate knowledge of all principals of ozone generation and its use in applications such as wastewater disinfection. Therefore, the in-house knowledge on correctly applying the technology is of the highest standard available in Australia.

The above information should answer many, although not all, questions that are likely to be raised on the application and use of ozone for wastewater applications. However much of the information presented will be necessary by consultants, design engineers and end users, to fairly assess the suitability of ozone as an alternative disinfectant.

If any additional information is required or you would like assistance with evaluating ozone for any particular application, or project, please contact

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