Water Treatment Using Non-Thermal Plasma
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Executive Summary

This report details the research, design, construction and testing of a project executed to help fill a gap in scientific knowledge regarding water treatment using non-thermal plasma. Plasma is an ionized gas and is classified as the fourth state of matter; the first three states are solid, liquid and gas. Lightning and plasma globes are two examples of when plasma can be generated as a result of a high voltage, electrical discharge in a natural and controlled setting.

More than one billion people across the world currently do not have access to treated drinking water. Untreated water can be contaminated with harmful microorganisms including Escherichia coli (E. coli) which can result in illnesses of varying severity. This can place a range of community members at significant risk, particularly those who are already ill, the young, and the elderly. It has been approximated that across the world, 1.2 million deaths a year can be attributed to poor water quality. Therefore, the provision of treated drinking water would result in improvements of health, sanitation, and lifestyle security.

An investigation of previous water treatment systems was completed in order to benchmark various designs to determine their benefits as well as limitations. This investigation acknowledged that chlorination as well as ozonation are currently two of the preferred methods for the disinfection and degradation of organic pollutants in water. However, both of these methods are not viable long term options especially for developing countries. Chlorination requires the ongoing replenishment of chemicals and ozonation systems use consumable parts which require replacing at a non-sustainable rate. Developing a system which does not require replenishing or exchanging consumables such as chlorine or UV lights for ozonation on a regular basis is more suitable for the areas most commonly affected by drinking water quality.

This project aims to fill a gap in current knowledge and to develop a working prototype allowing to investigate the effects of non-thermal (cold) plasma discharges and pathogen destruction in water. Currently there is a lack of research relating the characteristics of non-thermal plasma and pathogen inactivation in water. However, the by-products produced from non-thermal plasma, such as ozone and other particular radicals have been. In relation to water treatment, these by-products exhibit properties such as sterilisation, deodorisation, and decolourisation. Analysing the correlation between these properties when produced from non-thermal plasma and the resulting pathogen inactivation could lead to an effective alternate water treatment system being developed.

Testing was completed on a device in order to determine the potential of using non-thermal plasma for inactivating microorganisms. The success of the project was dependent on the concentration of ozone the device could produce and its ability to mix effectively throughout the water. Final testing was completed by placing the pathogen, E.coli into reverse osmosis water and treating it by exposing it to non-thermal plasma. This process was completed to determine how the microorganisms cell counts would cultivate as a result of the exposure to the non-thermal plasma, in comparison to the traditional ozonation and chlorination methods. The bacteria (E. coli), was cultured and grown as it is commonly used for testing in a laboratory setting to assess the efficacy of water treatment systems. It was also selected as it is commonly used as a tracer in determining the presence of other pathogenic organisms and therefore the resulting quality of water.
The device was subjected to multiple preliminary tests to determine the optimal input settings to achieve a maximal ozone output. At 275 Hz and 24 V, the device produced the highest average dosage of ozone with 0.52 mg/L without over heating the electrical equipment. Testing with (E. coli) was then able to be conducted to examine the device’s true ability to treat water at a microorganism level. Two independent trials were completed with 150 mL of (E. coli) contaminated, reverse osmosis water and it was evident that a 3 log reduction (99.9%) was achieved after one minute in both cases. Testing continued for an additional two minutes with samples taken at every one minute interval. Even with the additional exposure time, due to the number of plates available to incubate the treated water in, as per the one minute sample, a three log reduction was again confirmed. This result signifies that the system is capable of treating water at the microorganism level and that a proof of concept has been accomplished. This report will present the work completed on the project and its subsequent results in further detail.

The water treatment system that was designed and built was able to achieve its goal of a 3 log reduction of the organic contaminate (E. coli). The next stage is to investigate further into the recommendations for future work which are presented in the report. This includes suggestions for further development of the electrode configuration; optimising the electronics for performance as well as size; changing the source of the power supply; and continual testing to replicate the results already obtained as well as to ensure the device satisfies the World Health Organisations water quality standards. Lastly, as a result of the conclusions drawn from the current research, further optimisation, and testing, the device could one day be developed into a commercially viable solution to treat water.
Signed Statement

The content of this report is entirely the work of the following students from The University of Adelaide. The work is also to the best of our knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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The success of the project based on the goals set out by the team was reliant on the ability to test with the organic contaminate, Escherichia coli. Therefore we would like to acknowledge Dr Connor Thomas from The School of Biological Sciences at The University of Adelaide for his contribution in regards to the advice and testing facilities he was able to give us. We would also like to mention a special thanks to Dr Connor Thomas for his patience and spending his valuable time working with mechanical engineering students who had a lack of knowledge in this field of science.

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1: Introduction

1.1 Introduction

Clean water is an essential resource for sustaining human life by providing hydration and sanitation. However, currently more than one billion people worldwide do not have access to safe drinking water, particularly in developing communities and nations (WHO 2015). Unsafe water sources often contain high levels of harmful pathogenic microorganisms and other contaminants, which require appropriate treatment before the water can be safely used or consumed. Currently, there are numerous commercially available technologies commonly used to treat contaminated water; including membrane filters, reverse osmosis and chlorination. Such technologies have all been extensively researched and developed, they also exhibit limitations when being used in developing communities.

An alternative method of treating water is by creating non-thermal plasma, which is an ionised gas generated by electrical discharges between electrodes. Non-thermal plasma produces ozone and other reactive molecules useful for inactivating harmful pathogens in water. Whilst there are various methods for producing non-thermal plasma, it is traditionally generated in the presence of a gas such as air or helium. Non-thermal plasma can also be generated in a liquid however, this is generally considered more difficult and energy intensive, also minimal research has been conducted in this area.

1.1.1 Motivation

In a world with constant human expansion and a growing population, supplying enough safe water to meet an increasing demand is a challenging yet necessary problem for mankind to address. Water as a resource is abundant and covers 71% of the Earth’s surface, yet less than 1% of this is safe for human consumption (CIA, 2013). Developing innovative methods to treat water is vital for humans as a species to continually grow as well as develop, and the main motivation behind this project. The water treatment method being research is non-thermal plasma. The motivation behind the project using non-thermal plasma as a water treatment method is that plasma in general is an underdeveloped topic, with great potential.
2: Literature Review

2.1 Water Quality

To aid in understanding the significance of undertaking a project that aims to treat contaminated water, it is important to recognise the context of the problem. An investigation into the common types of water contaminations present in developing nations, and associated health issues that can arise is outlined below.

2.1.1 Water Contaminants

Water in developing communities and nations often contains high levels of organic and inorganic contaminants. Organic contaminants are usually pathogenic microorganisms such as bacteria and viruses, however they can also include a range of chemicals. Pathogenic microorganisms can cause a range of waterborne diseases as well as illnesses, depending on the concentration, particular strain of organism and environmental conditions.

Contamination of major waterways in developing nations is often due to a lack of sanitation and improper maintenance of major water ways. The water is predominately obtained from natural sources, and the severity of contamination is dependent on the quality of that source. An above ground source is often contaminated by debris upstream and may consist of both solid matter and pathogenic microorganisms. Contrastingly, underground water sources generally contain high levels of inorganic chemicals and have lower concentrations of pathogens (CAWST ND). In developing nations, the most common contamination source in water is a result of human and animal faecal matter. Faecal matter hosts a wide range of pathogens, particularly bacterial coliforms such as Escherichia Coli (E. coli) (UNICEF 2003).

2.1.2 Waterborne Diseases

Consumption of contaminated water is linked to 1.2 million deaths each year (CDC 2012) and poses a significant health risk to a range of people, especially children, the elderly and those who are already ill. Waterborne diseases can vary in type as well as severity, and can result in life-threatening infections (NHMRC 2011). Diarrhoea is the most common adverse health effect that accounts for 98% of waterborne pathogen related deaths, particularly among young children (CDC 2012).

Diarrhoea causes the body to frequently pass watery faeces and can result in severe dehydration as well as loss of vital salts and minerals. Diarrhoea is particularly severe in children who already suffer from malnutrition, which makes them more vulnerable to the effects of the illness (WHO 2015). Without adequate clean water to rehydrate the body, the effects of diarrhoea can be fatal.

Common diseases that can result in diarrhoea are Cholera and Schistosomiasis. These are reported by The World Health Organisation to be two of the main contributors to the Global Water Health Challenge. It is estimated that there are over 4.3 million cases and up to 142,000 people are killed annually within hours of infection of Cholera. Its impact is significantly increased because as it is extremely virulent, which means it can rapidly spread between children and adults alike (WHO 2015). Schistosomiasis is present in 240 million people and is an infection where microscopic adult worms inhabit the veins of the human host, which can result in severe morbidity.
2.1.3 Standards

The extreme adverse health effects that can result from consuming water with pathogens present has led to the development of strict guidelines to control the quality of water consumed by people. These standards are to be adhered to in most developed countries but compliance is often not possible due to the lack of economical viability for foundation of governing bodies. Most countries have introduced their own standards due to the variability of water sources and other cultural as well as financial restrictions. Despite the former restrictions, the World Health Organisation has produced guidelines for the control of global drinking water quality which is aimed to set the benchmark for all countries to achieve (WHO 2004). A more appropriate design specification for this project is to follow the Australian Drinking Water Guidelines (NHMRC 2011).

The quality of the water should be assessed by detecting all the pathogenic organisms present in the water. However, this is not always practical and instead it is common practice to use indicators. An indicator is an organism whose presence indicates pathogenic contamination and provides an indication that the sample is unsafe for human consumption (Gleeson & Gray 1997). The most effective indicator will be dependant on the testing equipment available and the end use of the water.

An effective indicator for assessing the safety of drinking water is Escherichia Coli (E. coli) (NHMRC 2011). E. coli is a faecal coliform and is unique because only pathogenic organisms can produce it (Gleeson & Gray 1997). This means its presence indicates the water is not safe for recreational purposes and poses a serious health risk (NHMRC 2011). The concentration of E. coli can be easily and cost effectively determined using a controlled incubation period as per Australian Standards, ASTM D5465, (2012). The desired concentration of E. coli present would be zero because this indicates there is no pathogens present, however this is not usually practical. Under Australian Standards for drinking water, the concentration of E. coli must not be detectable in any samples of 100 millilitres (AS/NZS 2007). Therefore, water that achieves Australian Standards is deemed safe for consumption.

2.2 Water Treatment Technologies

Currently, there are a range of commercially available water treatment technologies commonly in use in todays society. Such technologies include physical filters such as membrane filters and reverse osmosis, as well as chlorine which is a commonly used chemical treatment process. Each of these systems have advantages and limitations in their use, as detailed below.

2.2.1 Membrane Filters

A membrane is a physical filter that allows water to travel through, removing any solid matter and some microorganisms in the process. Membranes are classified as either microfiltration or ultrafiltration, depending on the size of the pores in the membrane. Microfiltration (MF) membranes have a pore size of 0.03 to 10 microns (1 micron = 0.001mm) and is effective at removing sand, silt, algae and some bacterial species. However, it is not a barrier against harmful viruses that can cause illnesses (Lehr & Keeley 2005). MF membranes have an average service life of three to six years however, fouling in the pores can reduce the service life by up to 50% (Wang, Hung & Shammas 2007). Membranes require regular cleaning with specific chemicals to remove such fouling to ensure the filter is performing effectively. Such chemicals are expensive and impractical for use in developing nations.

Ultrafiltration (UF) membranes are similar to MF, however have a smaller pore size of 0.001 to 0.03 microns. UF is capable of removing all particles removed by MF including some viruses, however it is not an absolute barrier (Lehr & Keeley 2005). The smaller pores increase the removal efficiency of the membrane, allowing UF membranes to be used as a sole treatment method. However, the smaller pores also become more susceptible to fouling and blockage. Membrane systems discharge up to 15% of the water being treated as waste. This waste water contains the contaminants however, in much higher concentrations and requires careful disposal (Lehr & Keeley 2005).
2.2.2 Reverse Osmosis

Reverse osmosis (RO) membranes are similar to the MF and UF systems previously discussed, however RO has a pore size smaller than UF. This makes RO membranes more effective at removing contaminants, as well as removing a larger range of viruses. However, these membranes also become easily fouled and require regular cleaning as well as back-washing. Assuming the membranes are properly maintained, they have a service life of approximately three to five years (Lehr & Keeley 2005). RO membranes also discharge a portion of water as concentrated waste.

2.2.3 Chlorine

Since the introduction of the chemical chlorine over the past 100 years, it has developed primarily into one of the most conventional water treatment process to disinfect untreated water sources. The introduction of the chemical chlorine to the untreated water is usually achieved by using chlorine in a compressed gas composite, Hypochlorite Solution (NaOCl) or as a solid Calcium Hypochlorite. This method is heavily based on having the consumable gas or solid composite of chlorine available near the water source or point of use.

Despite chlorine being used throughout the world and being attributable to the reduction of severe health problems as a result of increasing the availability of treated water consumption in developed countries, there are still significant issues with this process (CDC 2015). The first issue is that the chlorine remains in the water and without sufficient management, the chlorine levels can exceed the safe drinking limits of 4 ppm or mg/L (EPA 2010). A breach of these standards can cause irritation to the eyes and nose, plus it can also result in stomach discomfort as well as eventually developing into anaemia in some cases. The other issues with the chemical include sourcing and safely as well as cost effectively operating with the chlorination additive.

The risks presented have been carefully monitored in developed countries such as Australia but there is a fine line between water that contains pathogens due to insufficient treatment and water which has high levels of residual disinfectant agents. These risks are managed by large governing bodies in developed countries to ensure water supply companies are always operating within allowable limits. This oversight is not usually available in developing countries where it is not economically viable to provide governance (CDC 2015).
2.3 Plasma

2.3.1 Definition of Plasma

There are four states of matter, solid, liquid, gas and plasma, the first three states of matter solid, liquid and gas are commonly observed and generally well understood. However plasma is to some extent less established. Plasma is an ionized gas consisting of light electrons and heavy ions, the positive ions as well as the free electrons exist in proportions such that little to no overall electric charge is present. Plasma is present at a wide range of temperatures and pressures. Aurora borealis is an example of low pressure plasma being generated in the upper atmosphere. Fluorescent lamps are another example of where low pressure plasma can be observed. Earth’s sun, stars and nuclear fusion reactors are all examples of high temperature or thermal, plasma (Bonitz, Horing & Ludwig 2010). The properties of plasma and gas are similar, the notable dissimilarity is that plasma is a good conductor of electricity and is easily affected by magnetic fields whereas gases are not. Plasma in the use of water treatment possesses suitable properties such as the ability to dissociate molecular bonds, enhance oxidation, and stimulate chemical reactions through the production of free radicals (Chang et al. 1991). Plasma can be classified into two major categories thermal plasma (also known as hot or equilibrium plasma) and non-thermal plasma (also known as cold or non-equilibrium plasma) (Chang et al. 1991; Bardos & Barankova 2000). These two classifications of plasma will be discussed in the following subsections.

2.3.1.1 Thermal Plasma

Plasma is considered thermal when is has reached local thermodynamic equilibrium. This is achieved when plasma is generated at atmospheric pressure, 1 atm. At this pressure there is a high collision frequency of the electrons and heavy ions. Due to the high rate of collisions, the plasma is in thermodynamic equilibrium with the electron temperature, $T_e$. This is in the same temperature region as the heavy ion species temperature, $T_i$. Thermal plasma is also referred to as this because the ion temperature exceeds 100 eV. Thermal plasma can be obtained when gas flows through a high electrical potential so that the gas experiences thermal ionization and Joule heating whilst operating on a high power source with a high operating pressure (Fridman, Chirokov & Gutsol 2005); an example of thermal plasma is the plasma cutter. Thermal plasma is deemed unsuitable for water treatment applications due to its high ion temperature which will simply boil the water.

2.3.1.2 Non-Thermal Plasma

Ion temperature which is in the range of 2 eV for non-thermal and 100 eV for thermal plasma is considered the main distinction between the two types (Shenton & Stevens 2001). Non-thermal plasma is typically occurs at low pressure conditions and therefore has a low collision frequency. These conditions mean that the plasma in not in thermal equilibrium as the electrons gain more energy from joule heating. A common example of non-thermal plasma is neon lights as well as plasma balls. Properties of non-thermal plasma include low density of reactive free radicals, thermochemical non-equilibrium, low ionization rate, and excited state atoms. As thermochemical equilibrium is not reached, the resulting atmospheric plasma has an ion temperature close to the ambient temperature (Chang et al. 1991).

2.3.2 Generation Methods of Non-thermal Plasma

Non-thermal Plasma is produce through many means, the more common methods include dielectric barrier discharge (DBD), Corona discharges and pulsed arc discharge. The following sections are a brief description of these methods.
Dielectric barrier discharges, DBD, creates plasma through the configuration of a dielectric tube with a metal electrode. The cathode as it is normally positioned centrally inside the tube leaving a gap for which the working fluid may flow through. The dielectric tube then has a ringed piece of metal forming the other electrode known as the anode on its outer surface. The use of a dielectric material in the discharge gap prevents the formation of sparks by stopping direct electrical currents. A high voltage of either alternating or direct current in the kilohertz (kHz) frequency range is applied to the electrodes, generating an electric magnetic field (EMF). This EMF acts upon the working gas as it flow through the dielectric tube creating the plasma discharge and the electrical circuit becomes completed (Lu, Laroussi & Puech 2012).

The EMF charge generates joule heating within the working gas, this process involves the electrical energy being transferred to heat due to the resistance of the working gas between the cathode and anode. Joule heating increases the temperature of the electrons above their ionisation temperature which results in the production of non-thermal plasma. As the voltage is pulsed in the range of 0.05 to 500 kHz, switching the current on and off prevents the electrons heating, and hence regulates the output to purely non-thermal plasma (Lu, Laroussi & Puech 2012).

Corona Discharge

A corona discharge is a low current, high voltage, electrical discharge of non-thermal plasma through an air gap at approximately atmospheric pressure (Smith 2011). The high voltage generates an electric field which produces faint discharges around the electrodes edges, sharp points and thin wires radiating outwards. The faint discharges from the weak electric field creates plasma by drawing charged particles from one electrode to the other, closing the electrical circuit.

The high voltage breaks down the double bonds in oxygen, \(O_2\), molecules by accelerating electrons across the discharge gap. This produces oxygen ions due to the power dissipation allowing for the formation of ozone (Barlow 1994). A limiting factor on the production of non-thermal plasma from this source is that the electric field will break down and the corona will transfer in to a spark over the discharge gap if the voltage is increased to high Fridman, Chirokov & Gutsol 2005). There are two types of corona discharges, positive and negative, the only physical difference between the two is the polarity of the electrode. In terms of ozone generation, negative coronas are more advantageous as they produce approximately seven to ten times more ozone than that from a positive corona (Yehia, Abdel-Salam & Mizuno 2000). This was also supported by Awad and Castle (1973) whom stated the figure to be in the order of five to eight times more ozone.

Pulsed Arc Discharge

Pulsed arc discharge is a method that uses a high voltage discharge between two electrodes. The discharge in not constant but instead pulsed at a rate of 0.05 to 500 kHz. At this frequency, the arc can appear to be a constant stream to the naked eye. (Li, Chang & Guo 2011b). This process produces plasma in similar conditions to that of the dielectric barrier discharge method where joule heating raises the temperature of the electrons above their ionisation temperature. This method however does differ from the from the dielectric barrier discharge method as it uses an electrical arc to perform the joule heating on the electrons as opposed to a built up electric charge(Laroussi & Akan 2007). The resulting arc breaks the bonds in the oxygen, \(O_2\), molecules, much like the corona discharge does. This therefore produces oxygen ions which can lead to the formation of ozone (Barlow 1994). As this method uses a pulsed voltage source, it prevents the electrons from heating which could become thermal plasma. this is the same approach as the dielectric barrier discharge method discussed above. However as the pulsing rate can be as low as 10Hz and up to 500kHz, the electrons have the potential to reach a higher temperature than the dielectric barrier discharge method when operating at the lower frequency.
2.3.3 Electro-hydraulic Plasma Generation

When using non-thermal plasma to treat water, it is considered beneficial to complete the process in a submerged state through electro-hydraulic discharges. Electrical discharges submerged in water are classified into two categories, partial electrical discharges and spark/arc discharges. Partial electrical discharges are where the discharge current flows from one electrode but does not reach the other electrode. Whereas in the other case, the discharge occurs when the submerged spark/arc establishes a flow of current from one electrode to the other (Locke et al. 2006). After investigating the previously mentioned generation methods which includes, DBD, corona and pulsed arc discharge. Only the corona and pulsed arc discharges are deemed viable solutions which can be produced in a electro-hydraluic state.

2.3.3.1 Pulsed Corona Electro-hydraulic Discharge \textit{PCED}

A pulsed corona electro-hydraulic discharge differs from the basic in air pulsed corona discharge in air as the working fluid in this process is now water. Similar to the process in air the high voltage breaks water, \( H_2O \), molecules bonds by accelerating electrons across the discharge gap. The process now instead of producing oxygen ions due to the power dissipation will instead allow for the formation of ozone, hydrogen peroxide, monatomic hydrogen, hydrogen gas and other OH radicals (Malik, Ghaffar, and Malik 2001). A limiting factor on the production of plasma from a corona discharge submerged in water is the high electric field required to generate this discharge, which is in the order of \( 10^7 - 10^9 \text{ V/m} \) (Locke et al. 2006).

2.3.3.2 Pulsed Arc Electro-hydraulic Discharge \textit{(PAED)}

A submerged electrical discharge can be categorised into either a partial electrical discharge or an arc/spark discharge. Partial electrical discharges are where the discharge current flows in the form of ions rather than electrons, the current in this form of discharge does not reach the counter electrode. The pulsed arc electro-hydraulic discharge occurs in the form of a spark/arc which allows for the direct flow of current, transferred by electrons, from one electrode to the other. The arc/spark form of discharge is particularly difficult to achieve as the current will have a tendency to form ions and discharge partially through the water.

The characteristics of pulsed corona electro-hydraulic discharges and pulsed arc electro-hydraulic discharge systems are summarised in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pulsed Corona</th>
<th>Pulsed Arc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating frequency</td>
<td>( 10^2 - 10^3 \text{Hz} )</td>
<td>( 10^{-2} - 10^{-3} \text{Hz} )</td>
</tr>
<tr>
<td>Current (peak)</td>
<td>( 10 - 10^2 \text{A} )</td>
<td>( 10^3 - 10^4 \text{A} )</td>
</tr>
<tr>
<td>Voltage (peak)</td>
<td>( 10^4 - 10^6 \text{V} )</td>
<td>( 10^3 - 10^4 \text{V} )</td>
</tr>
<tr>
<td>Voltage rise</td>
<td>( 10^{-7} - 10^{-9} \text{s} )</td>
<td>( 10^{-5} - 10^{-6} \text{s} )</td>
</tr>
<tr>
<td>Pressure wave generation</td>
<td>Weak to moderate</td>
<td>Strong</td>
</tr>
<tr>
<td>UV generation</td>
<td>Weak to moderate</td>
<td>Strong</td>
</tr>
</tbody>
</table>
2.3.4 Advantages and Disadvantages of Plasma

There are various benefits that can be obtained from using non-thermal plasma over traditional water treatment methods. The by-products produced from the non-thermal plasma not only has the ability to treat water, it can also be used for its odour control and discoloration properties. Another advantage non-thermal plasma has over other mainstream chemical disinfection methods is that there are no consumables required to produce it. However, the main disadvantage for using non-thermal plasma as a water treatment method is that it does not have the ability to remove physical contaminates. Therefore, if non-thermal plasma was to remove larger organic contaminates such as sediment. A secondary course filter or equivalent will be required to operate in-conjunction with the non-thermal plasma system. This water treatment characteristic of not being able to remove physical contaminates is also shared with various other chemical disinfection processes.

2.3.5 Plasma By-Products

Non-thermal plasma generated by electrical discharges in liquid/gas mixes, depending on the type of the discharge and the input energy, will produce by-products. Plasma has both desirable and undesirable by-products, outlined in the following sections.

2.3.5.1 Desirable By-Products

Plasma initiates various chemical and physical processes, including electric field, ultraviolet radiation, overpressure shock waves and, of particular importance, formation of various reactive chemical species (Lukes et al. 2008; De Baerdemaeker et al. 2006). The chemical species such as hydroxyl radicals (OH-, H+, O-2) and molecular species (H2O2, H2, O3) contribute to the degradation of organic compounds as well as the inactivation of microorganisms in water. The process for the decomposition of organic compounds in water is oxidation, it is initiated by the plasma by-products which are mainly OH radicals, hydrogen peroxide and ozone. The main mechanism driving the oxidation process is the by-product, ozone.

2.3.5.2 Undesirable By-Products

A number of undesirable by-products are formed during the ozonation process of water from non-thermal plasma production, such as aldehydes and bromate (Von Gunten 2003). Nitrogen gas forms due to the production of aldehydes generated from the ozonation of the natural organic matter present in water. Generally, the level of formation surges as the ozone dosage is increased, however, the formation has been found to peak near an ozone dose of 5 mg/L (Am Water Works Res et al. 1991). The primary aldehyde produced is formaldehyde, which in large exposure will cause irritation to the eyes, nose and throat (Manual 1999). In the presence of bromide ions, bromate can form during ozonation. Bromate has been found to be carcinogen inducing, with the World Health Organisation issuing a maximum contaminant level of 10 g/L (Manual 1999). To reduce the amount of bromate produced, it is recommended to maintain the pH of the solution between 6 and 9, with 6 resulting in the smallest amount of bromate produced (Von Gunten 2003).
2.4 Ozone

Various methods have been proven to be effective at treating water and this includes ozone which is a highly unstable, reactive molecule. The powerful oxidant can be used for disinfection as well as oxidation purposes. However, it can also be used to control characteristics such as odour, taste and discoloration (Gunsen 2003). Ozone also has the ability to remove harmful pathogens by breaking down the cells nucleus and disrupting enzymatic activity which inactivates organic microorganisms (Gunten 2003; Langlais et. al 1991). This is a result of the organic microorganisms which include viruses, bacteria and pathogens inability to transmit or reproduce leading to their eventual death (DeBrum 2012).

The oxidant which is molecularly known as O$_3$ can be generated during an electrohydraulic discharge (Locke et. al 2006). This is achieved via a pulsed arc or pulsed corona discharge between two conductors which has either a gas or fluid and an electric field established between them (Locke et. al 2006; Alsheyab & Muoz 2007). If ozone is generated in the gas phase it can be stored for future use. However with current technology it is not deemed practical as its deemed a highly unstable gas with a short half-life especially in water.

Ozones half-life is dependent on the water quality and can range from seconds to hours (Majewski 2012; Gunten 2003). As a result, for ozone to be a viable water treatment process, production of the oxidant will be required to be completed on site. This will allow it to be used in place of or in conjunction with established chemicals such as chlorine, which can be stored. Chlorines ability to inactivate microorganisms has been established to be less proficient than ozone however, an exact value for this is not consistent between studies (Majewski 2012; Korich et. al 1990; DeBrum 2012). Additionally, microorganisms cannot develop a tolerance to ozone unlike chlorine and other decontaminators due to the greater oxidation strength (DeBrum 2012).

2.4.1 Treatment Process

Ozone treats water by inactivating microorganisms as well as pathogens by destroying their cells in water, using a process called oxidation. Oxidation is a chemical process where a molecule or atom loses electrons to a more reactive oxidising agent (Stanley et al. 2002). In the case of ozone, oxidation occurs due to two processes; via direct oxidation of organic and inorganic compounds from the ozone molecule, and indirect oxidation from radical ions that form when ozone decomposes (Langlais et al. 1991). Ozone is an oxidising agent and when it makes contact with the cell wall of a compound, it acts to dissociate an electron from the compound which destabilises the outer structure of the cell. When this process is applied repeatedly, it leads to abolishing part of the cell, and if sufficient oxidising agent is supplied it can destroy the entire cell. The hydroxyl free radical ions that form when ozone decomposes are also oxidising agents and act in a similar manner to destroy the cells.

2.4.2 Disinfection Parameters

Various parameters including pH levels, organic as well as inorganic constituents, solubility and temperature affect the performance of ozone as a water treatment method. This is a result of the ozone decay rate which directly affects the duration of the gas inactivating the microorganisms (Schulz et. al 2005). To optimise the ozone dosage to exposure time for a given log reduction of a pathogen, it is recommended that factors which decrease ozone decay rates are avoided (Schulz et. al 2005). However, the US Environmental Protection Agency (1999) state the opposite in which accelerating ozone decomposition is undesirable as the ozone dissipates faster. This results in further ozone required to inactivate the unwanted pathogens. The following sections describe further how the parameters mentioned earlier effect the decay rates and how it results in altering the treatment process.
2.4.2.1 pH Levels

The pH in water when being treated by ozone has been proven to have a minimal influence to the microorganism inactivation efficiency (US EPA 2001). It has been established that for higher water pH levels, the decay rate of ozone and the production of by-products increase (Langlais et. al 1991). While these factors do occur, another study also investigated the implications of various pH levels in water for ozone water treatment and concluded that the microorganism inactivation difference was negligible. To minimise the production of by-products, it is undesirable to have elevated levels of pH in the water as the ozone stability and ozone residual will decrease (Farooq et. al 1977).

2.4.2.2 Suspended Matter

Treatment systems that primarily use polluted water can contain high concentrations of organic matter and TDS (total dissolved solids). Any form of suspended organic or non-organic matter can decrease the rate at which ozone decays and promote slime growth. (US EPA 2001 as cited in Troyan & Hanson 1989). This is undesirable as providing safe, by-product free water is imperative for the safety of the consumer. The slime growth is attributed to the inability of the ozone to maintain a constant concentration (US EPA 2001 as cited in Troyan & Hanson 1989). Organic matter has been demonstrated to cause an assortment of outcomes in studies testing for the effectiveness of an ozone water treatment system. The microorganisms potentially can be protected from the organic matter, however this depends on the pathogen, the constituent as well as its size (Farooq et. al 1977). Including a bio filtration pre-treatment system has been proven effective to decrease the amount of total organic carbon as well as natural organic matter (Yavich et. al 2004). Minimising the quantity of suspended matter throughout the water treatment process will become an important factor in producing safe drinking water.

2.4.2.3 Solubility

Depending on the method used to treat water, solubility can have adverse effects on the efficiency of pathogen inactivation. Ozone when compared to other common water treatment chemicals such as chlorine, has a relatively low solubility capacity. However, ozone does provide stronger disinfectant capabilities than its counterparts (Korich et. al 1990; Majewski 2012). As a result, turbulent mass transfer or diffusion is recommended to mix the ozone gas throughout the liquid via some form of bubbling. When ozone is produced from a submerged pulsed electrohydraulic discharge, the ozone is absorbed by the liquid as a result of the reaction. Another factor that can influence oozones solubility is the temperature of the liquid; lowering the temperature results in a higher solubility (Majewski 2012; US EPA 2001).

2.4.2.4 Temperature

Water temperature has been established to be a key element in the process of inactivating microorganisms during ozone exposure (Schulz et. al 2005; Rennecker et. al 1998; DeBrum 2012; Owens et. al 1999). Tables 2 to 4 below all support this as they demonstrate the trend of increasing CT values for lower water temperatures. The term, CT value, refers to the ozone concentration vs exposure time required to achieve a specific log reduction in cells. This will be explained in greater detail in the following paragraph. As mentioned above, the trends demonstrated by the tables can be accredited to the colder waters decreasing the rate at which ozone decays and as a result slowing the disinfection time (Schulz et. al 2005). Other factors that are influenced by the water temperature include solubility and stability. These properties decrease as the temperature increases while the inactivation kinetics of microorganisms from the decomposition rate of ozone are deemed negligible (Katzenelson et. al 1974; US EPA 2001). Hence while the temperature does affect the CT value required to necessary the required log reduction. The temperature does not influence how the microorganisms become inactive.
2.4.3 Contact Time Values (CT values)

Understanding the exposure time and dosage of a disinfectant is important to optimise the water treatment process. If the sample being treated is exposed to a dosage for too long, by-products are more likely to arise. To help manage this CT (contact time) values are used to give an indication of the disinfectant requirements for a log reduction or percentage. The reduction or percentage is calculated from the microbial inactivation of the particular waterborne pathogens as well as microorganisms. CT values are calculated according to the following equation:

\[ CT = \text{ozone dosage} \times \text{contact time (mg.min/L)} \] (2.1)

CT values have the ability to be manipulated due to the linear relationship between the concentration and contact time for a given log reduction. This leads to the ability of increasing contact time for a reduction in disinfectant concentration while still maintaining the required CT value. This method would be useful for altering exposure time accordingly if there are limitations to the ozone production. Currently there is a lack of specific CT values for inactivating E. coli with ozone. However, Cryptosporidium which is acknowledged for its higher resistance to the oxidant, ozone can provide a sufficient base of information to develop a guide for how CT values can later be used for E. coli treatment.

2.4.4 Using Contact Time Values for Water Treatment

Traditional chlorination methods for water treatment which include using chlorine dioxide, chlorine and monochloramine have all been shown to be not very effective at inactivating Cryptosporidium (Korich et. al 2010). However, ozone has been shown to be the most effective method to control and inactivate Cryptosporidium when adequate dosage as well as exposure times are achieved (Korich et. al 2010; Schulz et. al 2005; Clark et. al 2001). This waterborne pathogen is often used in water testing due to requiring some of the highest CT values compared to other microorganisms. Giardia is another pathogen which is harmful to humans and has been established to be in the range of 15-30 times less resistant than its counterpart Cryptosporidium; while E. coli is less again (Schulz et. al 2005; Korich et. al 2010; Owens et. al 1999). E. coli is a harmful pathogen which is not permissible in water and is used as an indicator to determine if any other unsafe microorganisms are evident. However Cryptosporidium is another pathogen which can be used to determine if contaminated water samples have been subjected to enough treatment exposure time due to its higher resistance to ozone than E. coli as well as other microorganisms.

The CT values shown in tables 2 to 4 were all results from different studies investigating the correlation of ozone exposure and Cryptosporidium inactivation. The inconsistency in the values recorded between each of the studies were accredited by the authors as factors including measurement methods, pH levels, temperatures and the ozonation conditions. These effects were discussed above and how they can alter the effects of the ozone. It is evident that the results obtained all differ slightly, however they do provide a worthy approximation for the required CT values required to inactivate Cryptosporidium from ozone exposure. The log reduction used in the tables are equivalent to a percentage reduction i.e. 2 log reduction is the same as a 99 percent decrease and these can be calculated from the following equations:

\[ \text{Log Reduction} = \log_{10}(\frac{A}{B}) \] (2.2)

\[ \text{Percent Reduction} = \frac{(A - B) \times 100}{A} \] (2.3)

Where:
A = is the number of microorganisms before treatment
B = is the number of microorganisms after treatment
As water treatment is directly related to one’s health and safety, it is required to achieve an adequate log reduction. While no traces of microbial pathogens are desired, the following treatment requirements from Water Research Australia are mandatory. A 3 log reduction for protected surface water is the lowest treatment requirement for Cryptosporidium. However, a 5 log reduction is required when water has been in direct contact with animals or if it is susceptible to waste treatment upstream or nearby (Deere et. al 2014). Only Table 3 has sufficient data which goes past the minimum 3 log reduction requirement. Water treatment is required all year round even in cold climates where water temperatures can often fall below zero. As the water temperature decreases, the required contact time or ozone dosage increases which is supported with the data in tables 2 to 4.

The following is an example of how CT value tables can be used to determine the ozone dosage required to achieve a 3 log reduction (99.9%) of Cryptosporidium. The first example involves Cryptosporidium being exposed to ozone for one minute (contact time) while the temperature of water is 15°C. The second example involves an exposure time of two minutes and a water temperature of 15°C. The examples below have been calculated using data from Table 3.

Example 1.

\[ CT = \text{ozone dosage} \times \text{contact time} \]

\[ CT = 13.8 \frac{mg}{min} \times \frac{1}{L} \]

\[ \text{ozone dosage} = \frac{13.8}{1min} \]

\[ \text{ozone dosage} = 13.8 \frac{mg}{L} \]

Example 2.

\[ \text{ozone dosage} = \frac{13.8}{2min} \]

\[ \text{ozone dosage} = 6.9 \frac{mg}{L} \]

While these calculations were based on the data provided in Table 3, recalculating using CT values from Table 2 and 4 will produce different results. Those discrepancies could be a result of different experimental methods or testing conditions. It can be concluded that these tables are not entirely reliable as they are sensitive to the experimental variables. However, the data does provide a range of values to aim to replicate when conducting water treatment with an ozone process.

<table>
<thead>
<tr>
<th>Log reduction</th>
<th>Water Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>12</td>
</tr>
<tr>
<td>1.0</td>
<td>24</td>
</tr>
<tr>
<td>1.5</td>
<td>36</td>
</tr>
<tr>
<td>2.0</td>
<td>48</td>
</tr>
<tr>
<td>2.5</td>
<td>60</td>
</tr>
<tr>
<td>3.0</td>
<td>72</td>
</tr>
</tbody>
</table>
Table 3. CT values for Cryptosporidium inactivation from ozone (Rennecker et. al 1998)

<table>
<thead>
<tr>
<th>Log reduction</th>
<th>Water Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>20.1</td>
</tr>
<tr>
<td>1.0</td>
<td>32.7</td>
</tr>
<tr>
<td>1.5</td>
<td>45.3</td>
</tr>
<tr>
<td>2.0</td>
<td>57.9</td>
</tr>
<tr>
<td>2.5</td>
<td>70.4</td>
</tr>
<tr>
<td>3.0</td>
<td>83.0</td>
</tr>
<tr>
<td>3.5</td>
<td>95.6</td>
</tr>
<tr>
<td>4.0</td>
<td>108.0</td>
</tr>
<tr>
<td>4.5</td>
<td>121.0</td>
</tr>
<tr>
<td>5.0</td>
<td>133.0</td>
</tr>
<tr>
<td>5.5</td>
<td>146.0</td>
</tr>
<tr>
<td>6.0</td>
<td>158.0</td>
</tr>
</tbody>
</table>

Table 4. CT values for Cryptosporidium inactivation from ozone (DeBrum 2012)

<table>
<thead>
<tr>
<th>Log reduction</th>
<th>Water Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>0.5</td>
<td>4.9</td>
</tr>
<tr>
<td>1.0</td>
<td>9.9</td>
</tr>
<tr>
<td>2.0</td>
<td>20.0</td>
</tr>
<tr>
<td>3.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

The CT value tables above all have common limitations which could be improved upon. Two of the three tables do not account for more than 3 log reductions (99.9%). This can prove to be an issue when this was regarded the minimal reduction acceptable under particular conditions as stated above. Water temperature is a critical aspect when calculating the required CT value, two of the three tables include temperatures above 30°C whereas the other one only reaches 25°C. Even though it is evident the required ozone dosage or contact time is reduced, it is still important as by-products such as bromate can be produced. All of the tables values were derived from testing with an ozone generators while none were developed using a non-thermal plasma device which produces ozone as a by-product. This could lead to a further investigation into the correlation of water treatment from ozone due to non-thermal plasma production.

2.4.5 Measurement

Ozone dosages can be measured either in the gas phase, as the gas is produced, or in the aqueous phase, as the dissolved content that remains in the water after decay has occurred; referred to as the ozone residual (Langlais et al. 1991). Ozone in the gas phase can be measured at various points in the production process, such as the ozone generator output and the amount produced in the ambient air of the process area (US EPA 1999). However, it is often difficult to accurately determine the ozone dosage applied to water by measuring in the gas phase as the efficiency of transfer between the generator and the water is dependent on a number of parameters. The parameters which influence this process include the temperature, pH and immediate ozone demand of the water (Langlais et al. 1991).
An alternative method to ozone measurement is via the residual ozone content in the water. While there are numerous methods of achieving this, it is recommended that the indigo trisulphonate batch method (colorimetric method) is used (Gordon 2002). This method is very sensitive, precise, fast, and more selective for residual ozone than other methods (Langlais et al. 1991). The process involves comparing the difference in absorbance of light between a sample and blank solution, each with indigo trisulphonate added. This process can be conducted by a visual comparison, with a minimum detection limit of 10 g/L (US EPA 1999). However, the accuracy of this measurement method can decrease with a large presence of bromide ions and hypobromous acid in the sample (US EPA 1999).

2.4.6 Safety

Exposure to ozone at ground level in high concentrations is highly toxic and potentially fatal. It is recommended that adequate ventilation be provided to extract excess ambient ozone present in any areas testing is being conducted (US EPA 1999). The maximum exposure time for ozone at 0.08 ppm is four hours, while for 0.10 ppm the contact time decreases to one hour (Department of the Environment 2015). However, the human nose is relatively sensitive to ozone and can detect concentrations from approximately 0.05 ppm, before the concentration becomes a significant threat (US EPA 1999).

2.5 Summary

The need for safe drinking water is a global challenge which despite modern technological advances is still the cause of over 1.2 million people dying throughout the world (CDC 2012). The reason for which water develops into being unsafe and consequently endangering the lives of humans is a result of the harmful microorganisms known as pathogens, contaminating the water. This global challenge has two key hurdles to overcome, developing the suitable technology to safely treat the water and then to distribute it to those in need. The first hurdle has been extensively researched however the production of a water treatment system that does not require consumables as well as being cost effective has not been ideally met. The other technologies available whether they are physical or chemical have major drawbacks which has restricted their applicability to the one billion people who do not having access to safe drinking water (WHO 2015).

Non-thermal plasma produces several molecular species as a result of the chemical breakdowns which occur. One particular by-product which is produced from this process is the oxidant, ozone. Ozone characteristics in regards to treating water or air for microorganisms are well established. Plasmas generation process alters as a result of the ambient working fluid that it is produced in. In regards to water treatment, non-thermal plasma is either generated directly in the water or it is produced in the air. When non-thermal plasma is produced in air it is described as a pulsed signal discharge and when generated completely submerged in water it becomes an electrohydraulic discharge. The method selected affects the manner for which the by-products of the non-thermal plasma will mix with the organic contaminates. There is little visible difference between the two methods however, the different terminology is used to best represent the differences for achieving the breakdown of the working fluid.

The main advantage of using non-thermal plasma is to produce ozone as it is a powerful oxidant which has the capacity to inactivate harmful microorganisms such as bacteria and pathogens. Unlike chlorine which is commonly used throughout the world (WHO 2015), ozone has a greater oxidation capacity resulting in a more proficient method to inactivate the microorganisms cells. As ozone is also an unstable molecule, it returns to its oxygen form after the oxidation process. This means that it doesn’t remain in the water whereas for chlorine, it often leads to the generally found bad taste and odours. The effectiveness of ozone has been proven to be sufficient to kill Cryptosporidium which is well documented to require a greater CT value than E. coli.
Relating the production of non-thermal plasma with a pulsed signal to the eradication of bacteria is the fundamental gap in knowledge which this project aims to explore. The proof of concept will be verified using a small scale prototype designed to meet the operational criteria stated in the literature review. Due to the project’s limitations in regards to the safety and availability with handling bacteria, *E. coli* was selected as the appropriate live species to test the effectiveness of the prototype for. This research will hopefully deliver some additional knowledge to overcome the aforementioned first hurdle of providing safe drinking water to the world.
3: Project Specifications

3.1 Project Direction

The aims were established to help define the scope of the project. The project plans to improve the existing knowledge in the field of water treatment using non-thermal plasma. To achieve this,

- The project will investigate available literature in this field and establish any gaps in the research. By achieving this the project will contribute to the ever growing need of potable water.

3.1.1 Project Objectives and Aims

The final product of the project and thus the end objective as well as aims include:

- The design and construction of a water treatment system based on the gaps found within the available literature to be used as a proof of concept.
- Achieve a minimum 3 log reduction of \( E. \ coli \). This requirement was discussed in the literature review in chapter three of the report.
- Incorporate the characteristics of safety and reliability into the design where applicable.
- Ideally be suitable for long term use with minimal maintenance.

While the project aims to develop and construct a working water treatment system. A proof of concept at this stage is regarded higher in terms of the scope to help fill a gap in existing research. The following are further explanations of each of the characteristics and how they are related to the project.

3.1.1.1 Safety

An important aspect in the project is safety, this includes the potential end user, and those involved throughout testing as well as the construction phase. As a result, ensuring the risk to people and property is minimal throughout the life cycle of the water treatment device. The water treatment system is required to achieve a 3 log reduction of the pathogen \( E. \ coli \) to ensure the device has the potential to produce water safe for consumption as well as for it to be approved by the World Health Organisation at a later stage. The physical structure of the device will be designed to reduce the likelihood of injury to those operating or in vicinity of the system. As the device incorporates electricity at high voltages which is used to produce the non-thermal plasma as well as its by-products. Considerable preparation and risk management will be required before the construction to mitigate these issues. To help mitigate issues with safety, the designs and safety procedures are to abide by the Australian Standards or equivalent.

3.1.1.2 Reliability

Reliability influences the performance, safety and reputation of the water treatment system. Factors that are to be considered include producing a near constant quantity of electrical discharge which will result in plasma being generated. Producing a consistent amount of plasma directly relates to the system’s capability of inactivating microorganisms. This is a result of the ozone and radicals requiring certain exposure times for treating water. Due to ozones high oxidation properties, the exposure to the substance has the ability to subject the system to possible corrosion. As a result, selecting appropriate materials will be required to improve the reliability as well as longevity of the device and ensure it wont degrade when exposed to the conditions produced from the system.
3.1.1.3 Affordability

The price of an object is an important characteristic of the design and is often proportional to the target audience of the product. The project is primarily designing the system to be focused on readily available materials where possible. This could potentially lead to the device being deployed to third world countries if proven that it can treat water to the required standards. Therefore, material selection and system designs are important factors.

3.1.2 Project Scope

The scope of the project is to contribute to current scientific knowledge by investigating non-thermal plasma and its ability to treat water for harmful microorganisms. *E. coli* contaminated water will be treated by an operational system designed and constructed by the project group as a proof of concept. The scope of the project is limited to testing the prototype with the pathogen *E. coli*. This is due to occupational health, safety, and welfare issues in regards to handling dangerous biohazard substances. The project system variables such as discharge gap, voltage, frequency, and amperage will be analysed for their influence on the production of non-thermal plasma, its by-product ozone, and the resulting inactivation of *E. coli*.

3.1.3 Project Goals

The subsequent paragraphs entail the core objectives which the project required to be successful.

3.1.3.1 Design and Build of a System

Design and build a water treatment system which produces non-thermal plasma from a pulsed signal electrical discharge. The system will be designed to treat water containing microbial contaminants and achieve a 3 log credit reduction of *E. coli*. An initial prototype of the design was to be constructed after the preliminary report to allow sufficient time for testing. This goal directly relates to the project aim of providing treated water which is safe to consume and to test the effects of non-thermal plasma as well as its pathogen inactivation capabilities. The entire group are responsible for this goal however, William and Juliano were to handle the required ozone research. While Ruben and Adrian were responsible for the research as well as development of the device.

3.1.3.2 Test and Evaluation of the Prototype

Testing will be required to determine whether the device is capable of producing adequate dosages of ozone from non-thermal plasma. It is also necessary to determine if the water samples meet the required pathogen 3 log reduction as mentioned in the previous goal above. The water sample testing will be conducted with the support of The School of Molecular Biology at The University of Adelaide. The pathogen used for testing will be a strain of *E. coli* in order to determine if the system is capable of inactivating pathogens. The results from the testing will be used to modify the prototype, as required, in order to meet the projects aims. Testing was to be conducted by all group members while Juliano and William focused on the laboratory work with the assistance from The School of Molecular Biology. Ruben and Adrian were required to develop and ensure the device could produce the required output characteristics.
3.1.4 Project Sub Goals

The following objectives take the core goals and make them into smaller manageable ones which would be easier to maintain.

3.1.4.1 Determine Ozone Requirements

Investigate the required dosage as well as exposure times for ozone to inactivate pathogens in water. Developing an understanding of the effects these factors have on pathogen inactivation will be completed experimentally, conceptually or by existing research. This will help narrow down the scope of the project. This goal will be achieved when the group is satisfied that reliable CT values as well as knowledge into ozone pathogen inactivation kinetics are achieved. This goal was assigned to Juliano and William as they are focused their research in the field of ozone.

3.1.4.2 Determine Non-Thermal Plasma and Device Requirements

Explore the capabilities of non-thermal plasma and its ability to produce ozone to treat water. Defining the design requirements of the non-thermal plasma device will be required to start developing concept solutions. Devoting resources to this area early will prove to be beneficial to reduce the amount of potential design flaws later during testing. It will also provide an indication whether or not the scope of the project is feasible or not. This will be achieved when a comprehensive list of design requirements with a supporting literature review are developed and is accepted by the entire group. This goal is to be completed by Ruben and Adrian who will also have to liaise with other group members for the ozone requirements.

3.1.4.3 Design and Build a Non-Thermal Plasma Device That Can Produce the Required Ozone Dosage

Design a water treatment system which uses non-thermal plasma to produce adequate ozone quantities to inactivate microorganisms. The aim was to produce ozone from the device via some form of non-thermal plasma to treat the contaminated water. The prototype will be assessed on its ability to reduce *E. coli* by a 3 log credit reduction. The non-thermal plasma as well as ozone requirements to achieve the three order of magnitude reduction necessary is discussed below in the design criteria section of the report which is in chapter two. This will be achieved when all engineering as well as electrical drawings with all the required safety forms and procedures are completed. This goal will be integral as it is required to be completed before initial testing can commence. It is also required to fulfil part of the scope as well as aims for the project. This goal was to be completed by the entire group. However, Adrian and Ruben were responsible primarily for this goal while Juliano and William would assist where required.

3.1.4.4 Test If the System Can Achieve the Required Ozone Dosages

Testing the device to determine whether or not the system has the capacity to produce the required amount of ozone to inactivate the pathogen *E. coli*. The most effective technique to test for this is by a process called indigo trisulphonate batch method (colorimetric method) which can be used to measure the ozone quantity in mg/L (Gordon 2002). This will be completed when the group are satisfied that the device exhibits strong indications that it will be producing ozone consistently in the experiments. Completing this goal will be a significant achievement in the project as the final design of a working device as well as testing can continue. Juliano and William will conduct the ozone testing while Adrian and Ruben work to ensure the device is performing as desired.
3.1.4.5 Testing the System for Its Microorganism Inactivation Capabilities

Treat and test the \textit{E. coli} contaminated water for any reduction of the pathogen after treatment. The treatment as well as testing of the water will be conducted at the University of Adelaide by all group members with the assistance provided by The School of Molecular Biology. The water samples will be treated by the plasma treatment system and tested for its ability to reduce \textit{E. coli} to a 3 log credit reduction. This testing will determine how effective the water treatment system is and if it requires any adjustments, it will also assess if the design will meet the aims of the project and if alterations are required. This will assist in determining if the design is capable of inactivating \textit{E. coli} to the 3 log reduction.

3.1.4.6 Final testing

Testing the final device will be required to determine if all the objectives have been satisfied. This includes developing a reliable and safe non-thermal plasma water treatment system. It will have the capacity to treat water by achieving a 3 log credit reduction of \textit{E. coli}. This will be achieved with the assistance from The School of Molecular Biology and all group members. After the final testing for the device is completed, collating and analysing the data will be required.

3.1.5 Project Extension Goals

The following were determined to be extension objectives, and as such are not required for the successful completion of the project, though shall be undertaken if all other objectives are met.

3.1.5.1 Longevity and Robustness Testing

Subject the water treatment system to continuous working conditions to gauge how effective and robust the device will be. Completing repetitive testing will help determine if any parts need repairing, replacing, cleaning or any other special requirements. This will help determine if the device would be appropriate for users who require longevity as well as robustness as a result of their location, or economic situation.

3.1.5.2 Treating the River Torrens Water

A practical application test to show how effective the system is at treating various contaminants in conditions such as the River Torrens. This will also demonstrate the possible application of the treatment system being used in Adelaide. A possible attraction at the Ingenuity exhibition is to treat the River Torrens water. To prove to the public it is safe to consume and that the microbial contaminants have been reduced to safe standards, the group could consume the water.
3.1.6 Stakeholders

The project had two major stakeholders, the team members and supervisors. The four team members consisting of Ruben de Vries, Adrian Di Nardo, William Leonard and Juliano Paradiso, are regarded as the main stakeholders of the project. Each member will contribute and share an equal stake of the workload throughout the entire year. The team members were also responsible for ensuring that the project was completed on time, within budget, and at a satisfactory level in relation to the established aims as well as goals. The project supervisors, Dr Erwin Gamboa and Dr Cristian Birzer, primary role was to act as mentors for the team members. They also provided the students with guidance and technical knowledge to assist them in completing the required objectives. The project also included two other minor stakeholders from The School of Biological Sciences and the Electrical Workshop from The University of Adelaide who assisted in the projects completion. Dr Connor Thomas was used as a consultant through the biological testing phase and Mr Derek Franklin assisted in the systems electrical design period.

3.2 Design Criteria

The pulsed signal, non-thermal plasma water treatment system is required to produce ozone as well other radicals to remove harmful bacteria. This is to be achieved by designing the system based on the previously introduced generation methods. The following section details the design criteria in greater detail based on the required operating conditions established in the literature review.

3.2.1 Electrode Voltage

The production of ozone using pulsed signal discharge has three main defining characteristics, voltage, current and frequency. These characteristics affect the discharge method and the production rate of ozone which means all three need to be optimised to achieve the best results.

The voltage produced by the system is crucial to ensure the discharge achieves transmission between the electrodes. The breakdown voltage of the medium is a function of the discharge gap, material and electrode configuration. It is also heavily influenced based on the impurities present in the medium and therefore the voltage should be designed with a reasonable factor of safety to ensure the discharge can occur in the anticipated operating conditions.

The breakdown voltage in air can be approximated to be 3 kV/mm at atmospheric pressure and 20°C (Elert 2000). However, in regards to water it is common practice to assume that 6kV/mm is sufficient for water (Arora & Mosch 2011).

The working fluid for our design is a hybrid of air and water in equal proportions which means the required voltage will be the maximum necessary to facilitate transmission through 2mm of air as well as 2mm of water. From this it can be interpreted that 20kV will be sufficient to cross the discharge gap with a reasonable factor of safety of 166% to account for efficiency losses and impurities.

3.2.2 Frequency

To generate a discharge that is non-thermal, it is necessary to establish a pulsed signal frequency as a control signal for the step-up transformer. Literature suggests the operating frequency should remain between 100 to 1,000 Hz (Locke et al. 2006) and the control signal for the step-up transformer will adjust the range to 100 to 500 Hz (Dors N.D.). An indicator that the frequency is not in the correct range will be the evident production of vapour as the device is being operated (Dors N.D.).
3.2.3 Materials

The materials used to construct the water treatment container and electrodes are to be critically chosen as it is expected that the material will be in direct contact with pathogens as well as oxidising agents. As the oxidising effect of ozone is the main mechanism for the inactivation of pathogens, the materials used are required to be resistant to the oxidation and corrosion effects produced by ozone.

Ozone is a non-stable element that has a small half-life. The unstable molecule goes through an oxidising process where one of its three oxygen atoms detaches itself in an attempt to become stable again as an oxygen gas. This degrades materials which come into contact with ozone as well as producing fading and a loss of tensile strength (Row 2010). For the system to have a long life span the materials used will need to be ozone resistant. The following table contains a list of common materials and their rating in terms of ozone resistance.

Table 5. List of materials with their theoretical and practical ratings, under taken by Cole Parmer and Ozone Services respectively (Ozone services 2001)

<table>
<thead>
<tr>
<th>Material</th>
<th>Theoretical rating [Ozone Concentrations not specified]</th>
<th>Practical rating [Ozone Concentrations up to 100mg/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>304 stainless steel</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>316 stainless steel</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Aluminum</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Brass</td>
<td>NA</td>
<td>C</td>
</tr>
<tr>
<td>Bronze</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Copper</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>CPVC</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>EPDM</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>LDPE</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>Natural rubber</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Neoprene</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>Nylon</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>PTFE (Teflon)</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>PVC</td>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td>Silicone</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

Ratings – Chemical Effect
A) Excellent: No effect
B) Good: Minor Effect, slight corrosion or discoloration,
C) Fair: Moderate Effect, not recommended for continuous use, loss of strength & swelling may occur
D) Poor: Sever Effect, not recommended for any use

3.2.4 Contact Time Value Requirements

As previously outlined in chapter 2, contact time (CT) values are important information for determining the dosage and exposure time required to treat a certain pathogen with a given disinfectant. CT values for Cryptosporidium when using ozone as the disinfectant have been well documented, and subsequent CT value tables have been developed. Such tables indicate the necessary treatment time, ozone dosage and water temperature for a log level reduction of the pathogen. Compared to E. coli, Cryptosporidium has been acknowledged as a more resistant strain of pathogen which generally requires a higher CT value for a certain log reduction in cells.
The notion that Cryptosporidium is a more resistant strain of pathogen is supported below in Table 6 which lists some of the documented CT values for treating both of the pathogens with ozone at two different temperatures. To demonstrate the trends treating each of these microorganisms individually with ozone has, the information gathered from Cryptosporidium alongside the limited figures for *E. coli* are depicted below in Table 6. From the table, it is evident that decreasing the water temperature significantly decreases the ozone sensitivity of Cryptosporidium resulting in larger CT values required for the same order of magnitude reduction. Treating water contaminated with Cryptosporidium by means of ozone would then be suited to warmer tropical climates as the required dosage decreases significantly. The correlation for *E. coli* and temperature is not established and cannot be assumed to be the same as Cryptosporidium. This microorganism would be an effective pathogen to test with our device as it is well documented and is recognised for its higher resistance to ozone. However, due to difficulties with safety as well as resources, current research and literature will be required to indicate if the device is generating ozone effectively.

Table 6. Water treatment comparison of Cryptosporidium and *E. coli* with ozone (Block 2001; LeChevallier & Au 2004; Rennecker et. al 1998)

<table>
<thead>
<tr>
<th>Log reduction</th>
<th>Cryptosporidium (mg.min/L)</th>
<th>E. coli (mg.min/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5°C</td>
<td>24°C</td>
</tr>
<tr>
<td>2</td>
<td>32.5</td>
<td>3.54</td>
</tr>
<tr>
<td>4</td>
<td>60.7</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Currently there is a lack of details regarding treating water with detectable concentrations of *E. coli* via ozone CT values. The research isn’t established enough to truly reflect trends as well as correlations accurately for ozone and *E. coli* inactivation. As stated above, Cryptosporidium could not be used for testing however, *E. coli* can be. This is due to it being a less hazardous pathogen as well as having the resources to culture it in a lab. The purpose of testing *E. coli* in industry is not to set a performance standard, it is, instead used as an indicator for harmful contaminants. The device would be required to generate the necessary CT levels for these microorganisms to ensure the water is being treated sufficiently as a result of the exposure to no-thermal plasma. Comprehensive *E. coli* testing to develop accurate CT values for the pathogen has been left for future work even though research isn’t completely established. It has been deemed to be out of the scope for mechanical engineering but rather for the field of microbiology or equivalent.
4: Design Proposal

4.1 Component descriptions

The following sections entail descriptions of the components used to produce the pulsed signal, non-thermal plasma water treatment system.

4.1.1 DC Power Supply

The power unit for the proposed system was designed to match the power consumption required by all the components in the circuit. This consumption will primarily be from the step-up transformer which will require sufficient power to achieve transmission between the electrodes and to account for all the losses in the windings. The required power input is to be DC (Direct Current) with a voltage between 12 to 30V depending on the required output voltage, at 24V it is approximated to be 24,000V. This power supply will be a commonly available unit but could be replaced with a battery or solar panel for greater versatility.

The chosen system will be powered using a standard Australian wall terminal with a voltage of 240V and output a voltage of 12-30 Volts. These characteristics are to ensure the device can safely operate during laboratory testing but can also be replaced by a standard car or motorcycle battery for mobile applications. The best system chosen was the Wavecom PS-3005 Programmable DC Power supply which is a programmable 0-30V DC adjustable power supply rated for 150W i.e. 5 Amps at 30 Volts. This unit allows for highly accurate scientifically valid testing because the voltage and current can be controlled with reasonable accuracy.

4.1.2 Waveform Generator

The device will require a pulsed signal at a specified frequency to produce a pulsed signal discharge. The frequency is to be variable for testing purposes however the final prototype will have a constant frequency based on the optimisation testing. This frequency can exist in different waveform shapes as shown in figure 1.

![Waveforms](image)

Figure 1. Most common voltage and current waveforms a Sinusoidal waveform, Square Waveform, Triangle waveform and a Sawtooth waveform (Dokic & Blanusa 2014)
Function generators output particular control signals as a result of the adjustable input frequency. This makes them beneficial in relation to satisfying the design criteria of producing a pulsed signal to develop non-thermal plasma. From previously research discussed in the literature review; it is best to use a square wave form. Therefore, the waveform generator will be required to output a square wave form with a frequency range of 100 to 4,000Hz.

The chosen device for the purposes of testing was a GW Instek GFG-8250A which is further described in figure 2. This system is able to produce a very accurate (± 0.3Hz) output and can be varied easily during testing.

![Figure 2. Extract from GW Instek 8200A Data sheet](image)

### 4.1.3 Switching Device

The signal generated by the above waveform generator must be processed by a switching element. This element can be either a transistor (Bipolar or Unipolar or MOS) or diode depending on the operating conditions. The basic components of the elements are largely the same with the defining characteristic being the rated maximum voltage, current and frequency.

The selection of the switching element must account for the maximum operating conditions for the testing and the final product. The element must be able to withstand the high frequencies present during the testing and also the high voltages present during the water testing. However, none of the common switching devices available are able to withstand the high output voltages from the step-up transformer. As a result, the circuitry is to be designed such that the element is not directly connected to the output (secondary winding) of the coil.

![Figure 3. Graphic representation of common semiconductors (Dokic & Blanusa 2014)](image)
The frequency range necessary for the testing and the final product can range up to 4kHz with the current and voltage expected to remain below 10A and 30V respectively and therefore the only suitable elements is either the IGBT or MOSFET.

The IGBT (Insulated-Gate-Bipolar-Transistor) consists of three main components, the gate, the collector and the emitter it is able to withstand a voltage of 1,200 Volts, a current of 400A and frequency of 20kHz (Dokic & Blanusa 2014). The MOSFET or Metal-Oxide-Semiconductor-Field-Effect-Transistor has the same three components as the IGBT, in a different layout but is on average a lot cheaper to purchase in Australia. Comparatively the IGBT is more robust to higher voltages and current and will require a more complex, expensive driver circuit.

The MOSFET (Metal-Oxide-Semiconductor-Field-Effect-Transistor) shown in figure 5, was chosen as the switching element because it has a larger frequency range which is displayed in figure 4 and has been found to be more efficient as well as not dissipating as much heat during operations at 1-20kHz. The lack of performance at high voltage and/or current should not have a determinant impact on the systems performance. The MOSFET will require a driving circuit which can integrate the previously introduced waveform generator and the step-up transformer (Wilson & Laud 2014).

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Maximum voltage/current (V/A)</th>
<th>Maximum frequency (kHz)</th>
<th>Switching time (µs)</th>
<th>On resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode</td>
<td>General purpose</td>
<td>5,000/5,000</td>
<td>1</td>
<td>100</td>
<td>0.16 mΩ</td>
</tr>
<tr>
<td></td>
<td>Very fast</td>
<td>3,000/1,000</td>
<td>10</td>
<td>2–5</td>
<td>1 mΩ</td>
</tr>
<tr>
<td></td>
<td>Schottky</td>
<td>40/60</td>
<td>20</td>
<td>0.23</td>
<td>10 mΩ</td>
</tr>
<tr>
<td>Thyristors</td>
<td>SCR</td>
<td>5,000/5,000</td>
<td>1</td>
<td>200</td>
<td>0.25 mΩ</td>
</tr>
<tr>
<td></td>
<td>RCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GATT</td>
<td>2,500/400</td>
<td>5</td>
<td>40</td>
<td>2.16 mΩ</td>
</tr>
<tr>
<td></td>
<td>GTO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SITH</td>
<td>2,500/1,000</td>
<td>5</td>
<td>40</td>
<td>2.1 mΩ</td>
</tr>
<tr>
<td></td>
<td>MCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bipolar transistors</td>
<td>Darlington</td>
<td>1,200/400</td>
<td>20</td>
<td>8</td>
<td>2.24 mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4,500/3,000</td>
<td>10</td>
<td>15</td>
<td>2.5 mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4,000/2,200</td>
<td>20</td>
<td>6.5</td>
<td>5.75 mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>600/60</td>
<td>20</td>
<td>2.2</td>
<td>18 mΩ</td>
</tr>
<tr>
<td>MOSFET</td>
<td></td>
<td>500/8.6</td>
<td>100</td>
<td>0.7</td>
<td>0.6 Ω</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000/4.7</td>
<td>100</td>
<td>0.9</td>
<td>2 Ω</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500/50</td>
<td>100</td>
<td>0.6</td>
<td>0.4 Ω</td>
</tr>
<tr>
<td>IGBT</td>
<td></td>
<td>1,200/400</td>
<td>20</td>
<td>2.2</td>
<td>18 mΩ</td>
</tr>
<tr>
<td>SIT</td>
<td></td>
<td>1,200/200</td>
<td>100</td>
<td>0.55</td>
<td>1.2 Ω</td>
</tr>
</tbody>
</table>

Figure 4. Characteristics of common semiconductor power switches (Dokic & Blanusa 2014)

The MOSFET will require a driving circuit which can integrate the previously introduced waveform generator and the step-up transformer (Wilson & Laud 2014).
4.1.4 Step Up Transformer

The high voltage necessary to achieve the pulsed signal, electrical discharge will be generated by a step-up transformer. This device amplifies the low voltage from the power supply to the required high voltage using differences in the electric fields between the primary and secondary winding.

The defining characteristics of a step-up transformer are dependent on the application but primarily the most common are the input and output power with some consideration for the efficiency.

4.1.5 Treatment Container

The treatment container section is where the output from the electrical componentry meets the water and air to produce the ozone and inevitably eradicate harmful pathogens present. This subsection will feature the electrodes to inject the high voltage pulsed signal and the treatment containment system which will insulate the highly charged water from the user. The design considerations are that it must be large enough to hold the sample size necessary for testing and also sufficiently accommodate the electrodes.

The design process focused on four different characteristics, the sample size, maximum electrode length, seal for apertures and the material for construction.

4.1.6 Electrodes

The electrodes for the system were made from stainless steel bolts. Stainless steel bolts were selected as they are readily available, low cost and, as displayed in Table 5 in chapter 3, are able to provide a sufficient resistance to ozone. The configuration of the ground electrode included an 8mm stainless bolt with a nut welded to it to prevent any leaks occurring between the two threads. A rubber O-ring was selected to seal the submerged electrode against the base of the container, as seen in Figure 6. However, the high voltage electrode constructed by stainless steel was not submerged and was positioned so that it was bolted to the lid of the container. The configuration of the electrodes were point to point to create a concentration point for the arc/spark to form.

![Figure 6. The high voltage and ground electrodes, whilst in operation](image-url)
CHAPTER 4. DESIGN PROPOSAL Water Treatment Using Non-Thermal Plasma

4.2 Preliminary Design

The proposed system is required to produce a pulsed signal discharge between two electrodes to generate non-thermal plasma. This design is the result of reviewing several alternative concepts and finding the most appropriate solution for meeting the design criteria.

4.2.1 Proposed Configuration

The final concept solution that best suites the design criteria was selected to be the MOSFET based system. This system can achieve the voltage and frequency required for an arc to develop in either water or air. This design can be broken into two subsystems, the electrical componentry and water container. The outcome of the system will be based on the ability to produce ozone in both water and air.

The electrical componentry is to produce the pulsed signal, high voltage input to the electrodes through the use of the switching device and step-up transformer. The design criteria highlighted that the voltage should be at least 20,000 V to achieve arcing and the switching device should be able to operate at 150-500Hz.

The MOSFET switching device was selected to produce the required frequency to generate a pulsed signal output for the step-up transformer system. The device should be accurately and easily adjustable for testing and capable of operating effectively for frequencies of 150-500Hz at 30V.

The design process for the switching device involved reviewing similar electronic components which can withstand the design criteria. This included using a diode or transistor as a switch and a 555 timer to supply a switching voltage. The chosen device was a MOSFET because it is able to withstand higher voltage and frequency and can be accurately controlled using a waveform generator. The waveform generator is a GW INSTEK GFG-8250A in conjunction with a MOSFET IRF2907Z, both data sheets are available in appendices K and J respectively. This system is able to withstand over 75 V directly from the power supply which implies a 250% safety factor on the maximum operating condition of 30V.

The maximum operating conditions will be 30V and 500Hz, at these conditions it is anticipated that the MOSFET will experience high levels of heat dissipation. This can be managed by installing a heat sink to increase the surface area which will result in a higher rate of heat dissipation. There are guidelines provided by the manufacturer for the effective design of a heat dissipation system which is displayed on the following page.
Maximum Thermal Resistance of Heatsink, $\theta_{SA}$: (Seshasayee 2011)

$$\theta_{SA} = \frac{T_J - T_A}{P_D} - \theta_{JC} - \theta_{CS} \tag{4.1}$$

Table 7. Extract from data sheet of MOSFET IRF2907Z

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{\theta JC}$</td>
<td></td>
<td>-</td>
<td>0.45 $^\circ$C/w</td>
</tr>
<tr>
<td>$R_{\theta CS}$</td>
<td>Case to Sink, Flat, Greased Surface</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>$R_{\theta JA}$</td>
<td>Junction to Ambient</td>
<td>-</td>
<td>62</td>
</tr>
<tr>
<td>$R_{\theta JA}$</td>
<td>Junction to Ambient (PCB Mount. steady state)</td>
<td>-</td>
<td>40</td>
</tr>
</tbody>
</table>

$$\theta_{SA} = \frac{175(\circ C) - 45(\circ C)}{330(W)} - 0.5\frac{(\circ C)}{w} - 0.45\frac{(\circ C)}{w} \tag{4.2}$$

$$\theta_{SA} = 0.56\frac{(\circ C)}{w} \tag{4.3}$$

Table 8. Available Airflow to Thermal Resistance (Seshasayee 2011)

<table>
<thead>
<tr>
<th>Available Airflow(LFM)</th>
<th>Volumetric Resistance($\text{(Cm}^3 \times ^\circ \text{C)/w}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td>500 - 800</td>
</tr>
<tr>
<td>200</td>
<td>150 - 250</td>
</tr>
<tr>
<td>500</td>
<td>80 - 150</td>
</tr>
<tr>
<td>1000</td>
<td>50 - 80</td>
</tr>
</tbody>
</table>

Volume of Heat sink with only natural convection: (Seshasayee 2011)

$$V_{\text{Heatsink}} = \frac{Volumetric\ Resistance}{\theta_{SA}} = \frac{650(\text{cm}^3 \cdot ^\circ \text{C})}{0.56(\frac{^\circ \text{C}}{w})} \tag{4.4}$$

$$V_{\text{Heatsink}} = 1160.71 \text{cm}^3$$

This value is fairly high therefore, it is feasible to install a fan of roughly 500LFM, the resulting volume of heat sink is:

$$V_{\text{Heatsink}} = \frac{Volumetric\ Resistance}{\theta_{SA}} = \frac{115(\text{cm}^3 \cdot ^\circ \text{C})}{0.56(\frac{^\circ \text{C}}{w})}$$

$$V_{\text{Heatsink}} = 205.36 \text{cm}^3$$
The high voltage necessary to sustain transmission through the air and water will be achieved using a step-up transformer. This system should be easily controlled and be well insulated to ensure the system can operate effectively and safely. A design constraint is that the device must at least output 20,000 Volts and be able to operate at a frequency of 150-500Hz. The voltage output is determined by the systems design turn ratio which gives an indication of the potential difference between the input and output i.e. A 1:2 turn ratio system will output twice the input voltage.

The design process for this subsystem involved reviewing a wide range of large turn ratio devices which can deliver the required 24,000 volts from the low voltage input of 24V. These devices included a high-voltage power supply for a household microwave magnetron, high energy electronic spark system for flammable gas ignition and a variable speed motor controller. However, the best suited system was chosen to be a standard car ignition coil (Bosch SU12R) because it achieves the design criteria voltage effectively and can easily be controlled using a switching system.

The Bosch SU12R ignition coil is a common step-up transformer used for automotive applications such as creating a high voltage output to a spark plug for ignition in an internal combustion engine. This particular model is designed for common v6 and v8 engines which means its better suited for frequencies higher than 100Hz. The standard design operating conditions is inside an engine bay which generally operates in temperatures in excess of 4000C (Fournier and Bayne, 2007). This indicates the insulation should not cease working effectively during anticipated normal operating conditions.

The switching device and step-up transformer will be housed in a protective enclosure. This is to ensure the electronic equipment is insulated from any spillage and the user is not able to touch any exposed terminals. The design criteria for this casing was that the unit can withstand water spray and be large enough to store the coil, MOSFET and all relevant connection terminals.

The design process for the container was to review the appropriate waterproofing classification to ensure the enclosure is able to withstand the anticipated spillage in a cost effective manner. The chosen rating was IP65 which means it is protected from all dust ingress and can withstand low pressure jets as shown in table 9.

<table>
<thead>
<tr>
<th>IP Number</th>
<th>First Digit - Solids</th>
<th>Second Digit - Liquids</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP65</td>
<td>Protected from total dust ingress</td>
<td>Protected from low pressure water jets from any direction</td>
</tr>
</tbody>
</table>

The size of the enclosure was to be able to easily hold all the necessary equipment, therefore the minimum size was determined to be 180 x 180 x 90mm. The closest product available was 201 x 193 x 98mm which meets the minimum requirement sufficiently.

Figure 7. The enclosure shown with all components fitted
### 4.2.2 Overall Design

The final design was the product of the most effective solutions based on engineering innovation as well as conceptual solutions. The final system is a prototype which will be operated throughout the testing phase and therefore help establish the proof of concept. Figure 8 represents the final design solution.

The electrical layout of the device is important to consider when evaluating how effective the system can produce the high voltage and frequency necessary. The electrical layout displayed on the following page details the electrical system. It demonstrates how the power supply connects directly to the positive terminal of the coil, whilst the switching system and the waveform generator are connected to the negative terminal of the coil. This method allows the secondary winding to charge up until the negative terminal discharges the energy to the electrodes, thus creating a high voltage pulsed arc.

The other design consideration that required attention was the electrode material as well as separation distance. This is to ensure the electrical system is capable of producing non-thermal plasma in a water/air mix. The spark gap selected was 4mm with the water level directly in between at 2mm.

![Electrical schematic diagram of entire system](image)

Figure 8. Electrical schematic diagram of entire system
4.3 Design and Construction

The finalised design of the system as documented above in previous sections demonstrates the features which enables the device to be integrated together. This ensures the device can be easily fabricated and operated safely throughout testing.

4.3.1 Operation

The device’s operation was intended to be simple as well as to provide safety measures for all those directly and indirectly involved. The safety precautions are also reflected throughout the Safe Operating Procedures (SOP) which was developed to the University of Adelaide’s standards and approved by the project’s primary supervisor, Dr Erwin Gamboa. During the production of the guidelines, there were three safety concerns, the use of water, high voltage electricity, and the potential of being exposed to the electrical terminals.

Incorporating water into the system increases the risk management required to protect those operating or in close proximity to the device. A factor that requires to be mitigated is the possibility of spillage. Spillage from the device may lead to a person falling or, it could increase the likelihood of being the recipient of an electric shock due to the equipment not being insulated adequately. There are provisions in place to reduce the likelihood of spillage. This includes sealing a lid on top of the container during operation and a large tray surrounding the water hazard area to contain any spillage.

The high voltage electricity produced by the ignition coil can be lethal if adequate safety measures are not implemented and adhered to. The best means of protecting those in close proximity of the device is to sufficiently insulate the areas where high voltage electricity has the ability to be transmitted through someone. This can occur by either coming in contact with or being close enough to an exposed cable core which may also result in the device arcing. The only sections which are at a high voltage (>240 V) is the cable connecting the coil and electrode. As a result, a well insulated cable (rated for 60kV, which is 250% safety factor) and an extended section of insulation will reduce the likelihood of coming into contact with the junctions.

Overall, the operation of the device is expected to be safe and straightforward to use. This is because a core design focus was to provide a system which uses commonly available equipment and there was sufficient safety considerations to ensure the risks involved were reduced.

4.3.2 Fabrication

The final device required minimal fabrication because most of the componentry was readily available throughout common retailers in Australia. These components include the power supply, MOSFET, diode, and the ignition coil. However, some fabrication was necessary for the electrodes which was completed by The University of Adelaide Mechanical Workshop.

The assembly of the electrical components was completed by The University of Adelaide’s Electrical Workshop to reduce the likelihood of poor connections influencing the performance of the system. This assembly primarily consisted of connecting the different components with common automotive cable fittings which is appropriately sized based on the anticipated voltage and current in the circuit.

The fabrication practices of the project were to a standard which is only suitable for a small scale production. Fabrication should be adjusted to suite the optimised design after the commercialisation process is completed however, this step is beyond the scope of this project.

The fabrication can be completed using common electrical equipment and most of the work incorporated trimming cables and fitting appropriate connections between the devices. The result is a device which is applicable for developing countries to potentially produce and also improve the commercial scale manufacturing prospects in the future.
4.3.3 Operating Conditions

Throughout testing, the water treatment system was operated under laboratory conditions to reduce the variables which potentially can compromise the validity of the results. However, the system was still designed with consideration towards the final end user. Factors that appeared to influence the device’s performance included: the temperature of the electronics, temperature as well as pressure within the container, and any external forces such as wind or vibrations which could induce water turbulence.

Components when operating outside their optimum temperature range suffer from a loss in efficiency. This therefore suggests that the temperature rating of the overall device is dependent on the components that have the highest minimum and lowest maximum operating temperatures. Table 10 list the temperature ranges for the components in the system and provides the overall range for the device, which was found to be 0 - 40°C.

Table 10. Operating temperatures for the water treatment systems components

<table>
<thead>
<tr>
<th>Device</th>
<th>Minimum Temperature (°C)</th>
<th>Maximum Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode (1N582X)</td>
<td>-65</td>
<td>150</td>
</tr>
<tr>
<td>Mosfet (IRF 2907Z)</td>
<td>-55</td>
<td>175</td>
</tr>
<tr>
<td>Power Supply (PS3005P)</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Waveform Generator</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Ignition Coil</td>
<td>-10</td>
<td>400</td>
</tr>
<tr>
<td>Other materials</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Overall Rating</td>
<td>0</td>
<td>40</td>
</tr>
</tbody>
</table>
CHAPTER 5. TESTING Water Treatment Using Non-Thermal Plasma

5: Testing

5.1 Device Testing

Testing of the system took place in three major stages: preliminary testing, ozone production testing and testing with *E. coli*. These stages are outlined below in the following sections.

5.1.1 Initial Device Testing

Preliminary testing of the water treatment system was conducted to assess the suitability of the design and demonstrate that the device is capable of producing non-thermal plasma. From literature, it was identified that the amount of ozone produced in the water is proportional to the quality of the discharge and the resulting non-thermal plasma. Hence, it is beneficial for water treatment purposes to have a system that produces non-thermal plasma entirely in water. Initial testing established that the device was successfully able to generate non-thermal plasma in air however, producing it with both electrodes immersed in water was considerably more challenging. This was due to the additional energy required to develop a strong enough electric field at the tips of the electrodes which is required to initiate a discharge. After numerous trials with both electrodes immersed in reverse osmosis water and testing across a range of voltages and frequencies. It was concluded that the components used in the design were not capable of outputting enough energy for this configuration. Further testing was then conducted with a hybrid air/water electrode configuration. The configuration consisted of one electrode being immersed while the other was positioned above the water level.

The high voltage electrode was initially situated below the water level and the grounding electrode was above. The system was also tested at a range of voltages and frequencies however, was not able to generate a discharge or non-thermal plasma as the energy was dispersed into the water instead of to the other electrode. The electrode configuration was then reversed and a faint, intermittent discharge was produced with an input setting of 12 V at 100 Hz. After a total of four minutes of testing with this setup, the RFP50N06 MOSFET and 1N4751 diode both failed. These components were upgraded with a new 1N582x Schottky rectifier diode and an IRF2907Z automotive MOSFET after consultation with the electrical workshop at The University of Adelaide. Testing continued with the same setup to determine an appropriate discharge gap between the tip of the immersed electrode and the water surface. As the electrode would displace water, the volumetric measurements on the exterior of the container were wrong. This resulted in a trial and error approach to calculate the 150 mL water sample size. The system in the end was able to generate enough energy to complete the discharge across the air and then ground itself through the immersed electrode while still developing non-thermal plasma.

The water treatment system was tested using three different types of water to determine if a particular solution aided in the generation of non-thermal plasma. These three included: Adelaide tap water, regular reverse osmosis water, and a table salt, reverse osmosis water mix. When reverse osmosis water was used, the discharge was able to penetrate through the water and gain contact with the other electrode. However, this was not achieved for any of the other solutions. This was expected as reverse osmosis water contains minimal quantities of suspended matter and is also an effective insulator. A solid discharge stream was then able to be developed as the energy does not disperse throughout the water like it would have if it was a conductor. It was decided to use regular reverse osmosis water for all subsequent trials to reduce the amount of variables while testing with live microorganisms.
5.1.2 Device Testing for Absorbance

Testing of the system was conducted to determine the effect of the design inputs which are voltage and frequency on ozone output to optimise the systems pathogen inactivation capacity. This was achieved by measuring the absorbance of each sample over a select range of voltages as well as frequencies and then calculating the residual ozone concentration. Investigating the peak ozone concentration the device could output was critical to correlate the potential reduction of pathogens as a result of ozone dosage exposure. This correlation would be based on research established by the literature review above in chapter 3. An assessment of the device could then be completed to determine if further investigation for treating with organic contaminates is required.

The system was configured according to the results from preliminary testing that produced favourable plasma characteristics. The high voltage lead and electrode was positioned above the water, while the ground was immersed in the water. Whilst a suitable frequency was still unknown, preliminary testing demonstrated that the electrical components, particularly the MOSFET, increased in temperature considerably when the frequency was higher than approximately 500 Hz. This provided a reference to test at lower frequencies and to measure the amount of ozone produced. From literature, it was recognised that increasing the amount of power inputted to the system generally increased the ozone output. However, the system being tested utilises an ignition coil which has an inverse relationship between voltage and current. This means that for an increase of voltage inputted into the coil, the current decreases proportionally. The effect this relationship has on ozone production was unknown and hence testing was required.

To attain useful data, a number of variables were kept constant between tests. A sample size of 150 mL was used as this provided approximately 2 mm of water coverage over the immersed electrode. The high voltage electrodes vertical position was adjusted to achieve a discharge gap of approximately 4 mm by loosening the locking nuts it was attached to. Reverse osmosis water was used as it is a better insulator than regular tap water. This prevents the energy from the device dissipating through the water and therefore not developing a solid discharge for the plasma generation process. Whilst testing with tap water would be more applicable, using reverse osmosis water helped minimise the variables in testing due to ozone reacting with other substances present in other water sources. Whilst the initial temperature of the water could not be accurately controlled, it consistently measured at approximately 19°C. Lastly, the contact time for each test was kept to a constant one minute for initial testing.

5.1.2.1 Ozone Measurements

The indigo trisulphonate batch method was selected as the most suitable technique for measuring the amount of residual ozone. The indigo reagent is a blue solution that reduces in colour as it reacts with the present ozone. As the concentration of ozone increases in the sample, the indigo reagents transparent appearance will adjust accordingly. The ozone concentration for each sample can be calculated by measuring the absorbance of light at 600 nm. Then comparing this to the absorbance of a blank sample of reagent mixed with water which has not been treated.

An indigo stock solution was prepared using 10 mL of reagent which was made on each day of testing. This amount of reagent allowed for 20 samples, with 0.5 mL being added to separate 1 mL microcentrifuge tubes. After each test was conducted, a sample of water was extracted and added to the reagent as a 1:1 ratio. As ozone has a relatively short half-life, the samples were added to the reagent immediately after the system was turned off. This is to ensure ozone decay could be mitigated and accurate readings could be produced. Once the ozone is mixed with the reagent, the solution becomes stable for several hours.

Each test sample was analysed using a Bio-Rad SmartSpec 3000 UV/Vis spectrophotometer to measure the absorbance. The samples were transferred to plastic cuvettes, rectangular vials which has a path length of 10 mm that the machine is designed for. The spectrophotometer was set to measure the absorbance at 600 nm by selecting the OD600 setting. To provide a reference reading for other samples,
the spectrophotometer was zeroed with a blank sample. Samples were individually placed into the cuvette chamber, the Read Sample button was pressed and a value for absorbance was displayed. As the readings from spectrophotometers fluctuate, each sample was measured three times to achieve an average value to increase the accuracy of the results. The machine was also regularly zeroed with the blank sample to ensure consistency between the readings. The ozone concentration for each sample was calculated using the spectrophotometric volumetric method, identified by Gordon (2002), and outlined below.

\[
\frac{\text{Miligrams of Ozone}}{\text{Litre}} = \frac{\text{mg of } O_3}{L} = \frac{100(A_{\text{sample}} - A_{\text{blank}})}{(fbV)} \tag{5.1}
\]

where:
- \(A_{\text{blank}}\): absorbance of blank
- \(A_{\text{sample}}\): absorbance of sample
- \(f\): indigo sensitive coefficient, 0.42
- \(b\): pathlength of cell, cm
- \(V\): volume of sample

In this case, the absorbance of the blank can be neglected as the spectrophotometer was zeroed with it. The difference in absorbance for each sample compared to the blank is the resulting absorbance value displayed on the spectrophotometer. For this calculation, the volume of sample, \(V\), is the amount of water (0.5 mL) and excludes the amount of reagent.

5.1.3 Device Testing With \textit{E. coli}

An important factor of investigating the performance of the systems design was to test with organic contaminants in the water. \textit{E. coli} was selected to be the organic contaminate as it was commonly used throughout literature to assess the initial efficacy of water treatment systems. The primary aim of this testing was to achieve a 3 log (99.9%) reduction in cells. This will be used to validate the design as an effective water treatment system which is capable of removing contaminates at the microorganism level. The \textit{E. coli} reduction in cells. This will be used to validate the design as an effective water treatment system which is capable of removing contaminates at the microorganism level. The \textit{E. coli} cells were added to reverse osmosis water, as stated previously this was completed to mitigate the ozone reacting with other substances which will be also treated and to promote non-thermal plasma generation. Similarly to the preliminary testing, the water was measured to be at a temperature of approximately 19°C.

5.1.3.1 Device Parameters for Testing

The device underwent testing with the system operating at the established optimal settings to produce elevated concentrations of ozone. From maximising the output capacity of the main disinfectant ozone, it could be determined if the system would be capable of achieving a 3 log cell reduction. From previous testing where the ozone production was compared against the input settings, it was determined that the system consistently produced the highest concentration of ozone at 24 V and 275 Hz. These settings also provided a compromise between the ozone produced as well as ensuring the electrical componentry did not substantially increase in temperature.

A substantial increase in temperature would result in the electronics becoming heat soaked which reduces the effectiveness of the system or it can result in the device completely shutting down. Temperature increase was related to the operating time and throughout the preliminary testing, the device was only operational for one minute intervals. This was while the device was still being scrutinized over to produce a consistent plasma stream, and to save time on initial testing to allow for a longer period for optimising the input settings. The preliminary testing was also used to gain insight into the possible
quantity of ozone that may be produced and to note any observations of the overall performance; this included the temperature of the electrical components. Reducing the temperature of the electrical components was important for when final testing was completed with the organic contaminate E. coli. These trials were conducted for up to three minutes for each sample and if heat soaking occurred, the pathogen inactivation could have been reduced resulting in the true potential of the system not being reflected well.

5.1.3.2 Mixing

To ensure even distribution of both the bacteria cells and ozone throughout testing, bubbling was incorporated into the system to mix the water. Bubbling was achieved using an air pump, commonly used for small aquariums. Silicone tubing was attached to the air outlet of the pump with the other end situated in the container via a hole in the lid with a rubber grommet to provide a secure fit. Whilst the exact flow rate of air was unknown, the pump was set to the lowest output setting to provide enough air to mix the water without creating too much turbulence that disrupts the electrical discharge. Prior to testing using water contaminated with E. coli, several initial trials were conducted to confirm that the bubbling did not have a significant effect on the amount of ozone produced, as outlined in Appendix G.

5.1.3.3 *E. coli* Testing

*E. coli* is a live bacteria and therefore preparation was required to culture as well as grow the cells before they can be used for testing. *Escherichia coli* ATCC 25922 was the strain of bacteria developed as it is commonly used for testing in a laboratory setting to assess the efficacy of water treatment systems. This strain was cultured in a Luria Broth medium, with 25 mL cultures incubated overnight at 37°C. The cells were then harvested by centrifugation at 4000G for 20 minutes and resuspended in 5 mL of sterile water. For each test sample, 40 µL of the stock cell suspension was added to 150 mL of water. This provided an initial cell concentration of approximately 1,000,000 cells/mL for each sample.

After a sample was extracted, decimal dilutions were performed to provide a range of samples with different cell concentrations to analyse. Decimal dilutions involve taking a tenth of the sample and adding this to nine tenths of new sterile water. This dilutes the sample by one log and can be repeated for further log reductions. Such dilutions were crucial for testing as the approximate amount of cells that would be killed was unknown. For each diluted sample, 100 µL was then spread uniformly onto the surface of plates containing a Luria Agar medium and incubated overnight at 37°C to form into colonies. To obtain useful results, the number of colonies present after incubation for each sample should be approximately 50 - 300. Dilution was required as without knowing the expected amount of cell deaths, the amount of colonies visually present could have been far greater than 300. High colony totals are difficult to count as they begin to merge together. It is also a struggle when counting to differentiate between the individual colonies. Similarly, for a sample that has been diluted several times, there may be too few colonies to count. Hence, a number of dilutions were performed to determine approximately how many cells were being killed and the resulting log reduction of cells.
6: Results and Analysis

6.1 Design Specifications

6.1.1 Voltage

From the results displayed in Figure 9, it is clear that the voltage is a variable in relation to the production of ozone. This trend was supported by the literature review in chapter 3 in regards to the production of non-thermal plasma. The device as expected, exhibited a proportional correlation between the increase in voltage and ozone concentration. However, the results indicated that there were also physical limitations such as overheating of the electrical componentry and the penetration consistency of the discharge.

It can be concluded from the results in Figure 9 that the peak ozone concentration was produced at 30 V with a frequency of 500 Hz. However, at such a high voltage the electrical componentry began overheating. Whilst this output may be able to be sustained for one minute of testing, repeated and extended use would reduce the life of the components. Across the remaining tested frequency range, 24 V outperformed 30 V.

It was observed during testing that at both 24 V and 30 V, penetration of the discharge through the water occurred when the frequency was greater than 200 Hz. Conversely, partial or no penetration occurred for 12 V and 18 V across the frequency range. The results indicate that when the discharge penetrated, the amount of ozone produced was considerably higher than when there was partial or no penetration. Thus, it can be deduced that the ability of the discharge to penetrate through the water and contact the grounding electrode is a determining factor in the concentration of ozone. As a result, 24 V was used for all subsequent testing. Whilst the ignition coil is designed to operate at 12 V, there were no noticeable drawbacks with operating the system at 24 V for a majority of the testing. With further testing and development, the system may be able to operate at 12 V and still produce enough ozone to obtain a 3 log reduction.

Figure 9. Graph of ozone concentration against frequency to determine the optimum voltage
6.1.2 Frequency

Further testing was conducted at 24 V over a frequency range with smaller increments, as outlined in Figure 10. The purpose of such testing was to more precisely determine the frequency that corresponded to a maximum ozone production for the system and components used. The results show that the maximum value occurred at a frequency of 275 Hz.

As the frequency increases, the amount of discharges increases but the ignition coil also draws less current from the power supply. Whilst a guide for an appropriate frequency was sourced from literature, this relationship has not been extensively investigated. The results show that generally a higher number of discharges is more effective than fewer discharges with more energy. However, balancing these two variables is the key to maximising the amount of ozone produced. This could be due to the ignition coil having a specific frequency that it is designed to operate at that produces a maximum power output. Furthermore, the coil reduces in efficiency when not being operated at this frequency, and this is reflected in the data.

![Graph of ozone concentration against frequency at 24v](image)

Figure 10. Graph of ozone concentration against frequency at 24v

6.1.3 Discharge Gap

It was observed during testing that the positioning of the electrodes was an important factor in establishing a useful electrical discharge. The optimal discharge gap was found to be approximately 4 mm, with 2 mm separating the tip of each electrode and the water surface.

Initial testing demonstrated that when the immersed grounding electrode was covered with too much water, the discharge was inhibited from penetrating through the water and making contact with the electrode. In this case, it was assumed that the energy dissipated throughout the surrounding water as the discharge only travelled to the surface of the water and did not penetrate. Further testing confirmed that penetration of the discharge was vital in producing significant amount of ozone, and the results are included in Appendix G. However, it was also important to cover the electrode with enough water to maximise the amount of ozone produced. Hence, a trial and error method was used to determine a distance of approximately 2 mm between the tip of the immersed electrode and the water surface provided consistent results.
For the high voltage electrode providing the discharge, the optimal distance from the tip to the water surface was also determined. From literature, it is known that a reduction in the discharge gap increases the amount of energy transferred to the grounding electrode. Consequently, this increases both the amount of plasma and ozone produced. However, testing showed that when the electrode was positioned approximately 1 mm above the water, the discharge was interrupted by the water rising and surrounding the tip of the electrode. This occurred due to surface tension, as the plasma disrupted the surface of the water. A distance of 2 mm above the water avoided this while still providing enough energy to the grounding electrode.

### 6.2 Ozone concentrations

The initial testing of the system involved examining various device inputs such as voltage and frequency for their effect on ozone production for a duration of one minute. Based off these results, further testing was conducted at 24 V over a frequency range with smaller increments, as outlined in Figure 10. The purpose of such testing was to more precisely determine the frequency that corresponded to a maximum ozone production. It can be seen in Figure 10 that 275 Hz produced approximately 0.52 mg/L. From the CT value table outlined in Chapter 3.2.4, it can be concluded that this amount of ozone is sufficient to achieve at least a 4 log reduction in E. coli cells.

By comparing the data displayed in both Figure 9 and Figure 10, it can be seen that there are inconsistencies in the measurements of ozone. For example, at 24 V and 300 Hz approximately 0.13 mg/L of ozone was measured in the first test while 0.45 mg/L was measured in the second test. This difference can be attributed to a range of systematic and random errors. Firstly, the absorbance readings displayed by the spectrophotometer fluctuate. However, without enough time to warm-up and calibrate (approximately half an hour), the readings can vary by as much as 100%. To counter this, the absorbance for each sample was measured three times and averaged. Inconsistent use of the pipette can also result in different amounts of water being drawn and added to each sample of reagent. While this does not affect the absorbance readings, it provides an incorrect value when converted to a concentration as the sample size of water is assumed to be a constant 0.5 mL. In the first trial, only one sample was taken for each voltage and frequency setting. Ideally, three samples should have been tested for each setting to provide an average value.

### 6.3 E. coli Level Reductions

Developing correlations between literature and ozone production was important to understand whether or not the device could potentially treat for microorganisms. Testing with bacteria was then required to confirm whether or not the information gathered from literature was applicable for this specific application. Two independent trials were conducted with E. coli with each test containing three, one minute interval treatment times. As listed below in Table 11, both control samples contained E. coli colony counts of 2.62 and 4 million cells per millilitre respectfully. For a one minute exposure time, both cases achieved a 3 log reduction (99.9%) of E. coli. After two minutes of treatment time, the water was exposed to further disinfection and additional reductions of E. coli were achieved. The full extent of the reduction was not quantifiable as the process which enables one to count the surviving colonies for a greater than three level log reduction was not established. This was due to a lack of laboratory resources at the time of testing with E. coli.

There was a correlation between the increase in contact time and the amount of ozone produced throughout both cases as depicted below in Table 11. The largest increase of ozone production was calculated to be in the first minute of testing. After this duration, ozone levels continued to increase however at a slower rate. However, the first test did exhibit an unexpected result where the quantity of ozone being produced decreased. It was uncertain why this result occurred; however after analysing the issue, possible sources for the decrease were identified. The device may not have established a
consistent strong discharge throughout the entire minute of treatment time and therefore reduced the production of plasma. An error in collecting the required 1:1 ratio of treated water and the indigo reagent solution may have been the cause of the reduction. Lastly, the device may not have bubbled the ozone throughout the batch of water efficiently to ensure no isolated concentrations would develop near the electrodes. This would result in inaccurate ozone readings across the entire treated water sample and the possibility of *E. coli* not being treated. The last minute of treatment did however operate as expected for both cases and produced strong concentrations of ozone as listed below in Table 11.

Table 11. Two independent *E. coli* testing results with constant device inputs across one minute intervals.

<table>
<thead>
<tr>
<th>Test Samples</th>
<th>Voltage (V)</th>
<th>Frequency (Hz)</th>
<th>Exposure Time (min)</th>
<th>Ozone Produced (mg/L)</th>
<th><em>E. coli</em> Colony Count (cells/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control 1</td>
<td>24</td>
<td>275</td>
<td>0</td>
<td>0.00</td>
<td>2,620,000</td>
</tr>
<tr>
<td>1</td>
<td>24</td>
<td>275</td>
<td>1</td>
<td>0.42</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>275</td>
<td>2</td>
<td>0.36</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>275</td>
<td>3</td>
<td>0.60</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>Control 2</td>
<td>24</td>
<td>275</td>
<td>0</td>
<td>0.00</td>
<td>4,000,000</td>
</tr>
<tr>
<td>1</td>
<td>24</td>
<td>275</td>
<td>1</td>
<td>0.44</td>
<td>3,500</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>275</td>
<td>2</td>
<td>0.54</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>275</td>
<td>3</td>
<td>0.69</td>
<td>&lt;1,000</td>
</tr>
</tbody>
</table>
7: Conclusion

7.1 Conclusion

This section outlines the achievements of the project, with reference to the aims as well as primary and extension goals. Recommendations for future work are also presented, including suggestions for optimising the device, further testing, and commercialisation. The device was designed and constructed to establish that the concept of microorganism levels are able to be reduced via this system. It is recommended for future work the experimentation is continued to confirm trends that were established during the testing phase.

7.1.1 Achievements and Outcomes

The design, construction and testing of the non-thermal plasma water treatment device along with the subsequent analysis, found that both of the primary goals and aims were achieved. Due to the compounding delays throughout the entire project, both of the extension goals were failed to be satisfied. The summary of the aims and goals is as follows:

- The design and construction of the water treatment system was completed based on the gaps found within the available literature and was used as a proof of concept solution
- The water treatment system achieved a minimum 3 log reduction of the organic contaminate, E. coli in two independent trials
- The device was designed to be safe and reliable

*All exposed wires and electronic components prone to overheating during testing were protected in a safety electrical box. For ease of manufacture and component replacement, commonly available parts were used and approximately 90 tests were conducted during testing as well as development.*

- Ideally be suitable for long term use with minimal maintenance

*The device does not rely on consumables such as chemicals, filters and UV lights unlike various other treatment methods. Without continual testing, the longevity and maintenance schedule for the device and its individual parts could not be confidently established.*

7.1.2 Primary goals

7.1.2.1 Design and Build of the Water Treatment System

A device which could produce a pulsed signal discharge was designed and constructed to meet the requirement of generating non-thermal plasma. The non-thermal plasma generated was capable of producing measureable concentrations of ozone as required per the literature review. Therefore an ozonation treatment method was achieved as a result of the pulsed signal discharge.

7.1.2.2 Test and Evaluation of the Prototype

Testing with the microorganism E. coli permitted the device to be tested with live bacteria. The device was then able to be tested for its ability to achieve a specific log reduction. From the two independent trials, in which the device was treating reverse osmosis water contaminated with E. coli, a minimum 3 log reduction was achieved in a one minute interval and each consecutive minute from there onwards.
7.1.3 Sub Objectives

7.1.3.1 Determine Ozone Requirements

The research conducted in the literature review established that there was a lack of applicable CT values or general ozone dosage concentrations for E. coli inactivation. However, the pathogen Cryptosporidium had extensive sources for ozone treatment in the form of CT value tables to achieve various levels of reduction in magnitude. It was confirmed that E. coli has a greater sensitivity to ozone than Cryptosporidium and therefore required a lower dosage for the same reduction of cells per sample volume. A range based on the available literature for ozone production was achieved and was used in the testing process to determine the effectiveness of the device.

7.1.3.2 Determine Non-Thermal Plasma and Device Requirements

The literature provided the guidelines as well as the method to generate the non-thermal plasma and the resulting ozone. These specifications were developed into the system design criterion to achieve these requirements. This was indicated by the successful transmission of the pulsed signal discharge between the two electrodes.

7.1.3.3 Design and Build a Non-Thermal Plasma Device that can Produce the Required Ozone Dosage

After achieving objective 7.1.2.2, it was possible to construct a device which was able to generate a high voltage, pulsed signal discharge. The discharge produced non-thermal plasma and using the indigo testing method, it was calculated that ozone was being produced in quantities up to 0.55 mg/L. This correlated with the documented literature and was within the range expected to be sufficient for treating E. coli for small exposure times.

7.1.3.4 Test if the Non-thermal Plasma Device can Achieve the Required Ozone Dosages

Continual testing was conducted by varying the voltage and frequency to measure for the peak ozone production. This was achieved by measuring the absorbance of the sample after it was mixed with an ozone absorbent reagent. The results indicated that the voltage and frequency could be optimised at 24 V and 275 Hz respectively. These input settings were used for all additional testing to ensure the ozone production was at an optimal rate for this device.

7.1.3.5 Final Testing

The final testing was conducted to examine the devices performance in inactivating E. coli cells using growth mediums supplied by the School of Biological Sciences at The University of Adelaide. The projects goal to achieve a 3 log reduction (99.9%) was accomplished twice in independent trials using the optimised settings. The original water samples containing E. coli had cell counts of 2.6 and 4.0 million cells/mL and these were reduced to less than 1,000 and 3,500 cells/mL in one minute respectively. The results satisfied the primary goal 1.2.2 of the project as it had a sufficient reduction and was able to repeat the results in a secondary independent trial.
7.1.4 Extension Goals

7.1.4.1 Longevity and Robustness Testing

The reliability testing of the system was not explored as a result of the compounding delays throughout the project. This was reflected by the time budget, the limited amount of time available to conduct research, design, construct and experiment. It also refers to the lead times when conducting tests with biological contaminatees and availability of laboratory space as well as following all correct procedures. It was deemed more beneficial to prioritise producing repeatable results instead of identifying the breaking point of the system. The achievement of accurate and theoretically valid results was more beneficial to the project and the systems future.

7.1.4.2 Treating the River Torrens Water

Water from the River Torrens was not tested due to time constraints. It was also deemed more beneficial to validate the system using water of known characteristics. In addition, with reference to the group consuming the water, this would be beyond The University of Adelaides Ethical Research Code as further testing would be necessary to guarantee there are no risks involved with this practice.

7.1.5 Future Work

The future of the project is to optimise and commercialise the prototype system which was developed and tested. The prototype was designed to further research and knowledge in the area of plasma water treatment. There is extensive product development beyond the scope of this project that will be necessary to create a system to be ready for commercial uses, humanitarian purposes or general use.

7.1.5.1 Optimisation

The design chosen for this project was constrained by time and budgets available. However, further optimisation beyond the scope of this project is possible to create a more efficient means of producing the ozone necessary for water treatment. There are two key areas which could benefit from further development; better mixing in the water container and an enhanced step-up transformer.

The first improvement is to introduce better mixing in the water container which would better distribute the ozone throughout the sample. This is important as the ozone is only produced around the discharge and is not likely to be uniformly distributed in the container. Further study is necessary to ensure the mixing is sufficient to guarantee the E. coli destruction is consistent throughout the entire sample. Examples of mixing systems may include incorporating rotating blades or circulate the water as a closed system.

The voltage was a key design criteria of the system because it has to be sufficient for the discharge to occur and also dictates the distance between electrodes. The chosen system was a standard ignition coil from a car which was able to produce approximately 30kV but other systems are able to produce higher voltages. This would allow for more versatility in the electrode design as the separation distance can be increased or more discharge points could be created. Both of these options may create more ozone in a shorter time period, however it is important to note that the power consumption will likely increase.
### 7.1.5.2 Reach Safe Drinking Standards for Other Pathogens

An extension of the optimisation is to conduct testing for other pathogens to provide a more extensive scientific proof that the device makes the water safe to consume. The aim of this project was primarily to test for E. coli because its existence represents the presence of other harmful pathogens (NHMRC 2011). However, a sufficient reduction of E. coli should be supported with data of the devices ability to destroy other harmful pathogens.

The source of the water will heavily dictate the pathogens present but testing is necessary to provide validation that all harmful pathogens are removed. This could be benchmarked to systems that are commercially available today. The best example is the LifeStraw GO produced by Vestergaard which guarantees a 3 log reduction of waterborne protozoa and 6 log reduction of waterborne bacteria.

Table 12. Pathogen removal of the LifeStraw GO by Vestergaard (Lifestraw S.A. 2015)

<table>
<thead>
<tr>
<th>Waterborne Bacteria Removed (99.9999%)</th>
<th>Waterborne Protozoa Removed (99.9%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esterichia Coli (E. coli)</td>
<td>Giardia Lamblia (Beaver Fever)</td>
</tr>
<tr>
<td>Campylobacter</td>
<td>Cryptosporidum Parvum</td>
</tr>
<tr>
<td>Vibrio Cholera</td>
<td>Entamoeba Histolytica</td>
</tr>
<tr>
<td>Pseudomonas Aeruginosa</td>
<td></td>
</tr>
<tr>
<td>Shigella</td>
<td></td>
</tr>
<tr>
<td>Salmonella</td>
<td></td>
</tr>
</tbody>
</table>

Following the above testing it would be beneficial to review the destruction efficacy against all common harmful pathogens. The World Health Organisations (WHO) compilation of pathogens which have the potential to be transmitted via drinking water is located in Appendix L.

### 7.1.5.3 Commercialisation

Once the device is optimised there is the potential for the system to be commercialised and made available for humanitarian purposes or use by the general public. This step will require significant development and testing of the final design to produce a product that meets consumer regulations.

Further development will ensure the device is completely safe in any foreseeable event that a user may experience. Since the aim of this project was to produce a system that can be used for humanitarian purposes it is important to keep the cost minimal while maintaining safety. A realistic life span of the product should be determined and a life cycle analysis should be conducted to ensure its environmental impact is minimal.
References


CAWST (ND). *Water Treatment Implementation for Developing Countries*.


Lehr, Jay H et al. (2005). Water encyclopedia: oceanography; meteorology; physics and chemistry; water law; and water history, art and culture. John Wiley & Sons, Inc.

Li, Oi Lun Helena, Jen-Shih Chang, and Yiping Guo (2011b). “Pulsed arc electrohydraulic discharge characteristics, plasma parameters, and optical emission during contaminated pond water treatments”. IEE Electrical Insulation Magazine 2.27, pp. 8–17.


Matsumoto, Takao et al. (2012). Non-Thermal Plasma Technic for Air Pollution Control. INTECH Open Access Publisher.


A: Work Breakdown Structure

The work breakdown structure has evolved with the project to better outline the work necessary to achieve the project's goals. The main derivations have been in the testing procedures which is a result of guidance from The University of Adelaides Microbiology department and the equipment available to the project. There were also some changes in the construction section with the device no longer requiring a flow control system.

This breakdown gives an indication of the process which was used to take a gap in the research and ultimately produce a device which can meet the goals of the project. The work was completed by all four students with consultation from workshop staff, supervisors and other staff at The University of Adelaide.

In the early stages of the project there was an extensive amount of time spent finding the gaps in the existing technology and knowledge which was fundamental to establishing the aims and goals of the project. From this point the design criteria for the proposed system had to be developed and the testing protocols had to be developed in parallel to ensure the time deficit can be alleviated. The built device and testing all came together in section 4 when the construction and testing practices were tested to determine if the project's goals were or can be achieved.

- **Literature Review**
  - Research market for existing knowledge and technologies
  - Identify gap in existing technology
  - Research drinking water standards for E. coli and Cryptosporidium
  - Investigate plasma generation and key design specifications
  - Investigate the effect of ozone on pathogen inactivation

- **Design**
  - Create plasma treatment system design specifications
  - Initial concept design of plasma treatment system
  - Initial concept design of integrated system
  - Preliminary design of all systems
  - Critical design of all systems
  - Create engineering drawings

- **Construction**
  - Organise construction method
  - Source materials
  - Construct plasma generation system
  - Construct water containment system
  - Integrate system

- **Testing**
  - Organise laboratory with necessary facilities
  - Develop method for testing
  - Complete risk assessment and safe operating standards
  - Source and prepare equipment for ozone testing
  - Conduct ozone testing
  - Optimise the device based on the ozone production

- **Deliverables**
  - Project Charter
  - Preliminary Report
  - Ingenuity
  - Final Report

- **Extension Goals**
  - Longevity testing
  - Test prototype using water from the River Torrens
  - Testing of plasma system for pathogen inactivation
  - Interpret and analyse data
B: Gantt Chart

To aid in completing the goals of the project within the budgeted time, a Gantt chart was produced. This computer aided project management tool represents the timeframe of the entire project while also allocating resources to ensure each task gets completed. An initial Gantt chart was constructed with all of the milestones of the project and a guideline of the time needed for the completion of the project goals within the available time budget. This initial chart had to be adaptable because if the project fell behind, new provisions could be included to possibly repair the time deficit.

The Gantt chart developed over time, in accordance with the project. The project started with an initial concept and a goal to find a gap in the literature which it could focus on, this then produced changes to the scope and direction of the project. As a result many of the initial tasks undertaken would be repeated for each scope and direction change. The final Gantt chart now appears to have large holes early in the project which is common for research based project because there is an inherent risk that the design criteria could take longer than expected to be developed.

The major changes to the Gantt chart were to best account for the time lost during endeavours into developing the design criteria of the device which is the foundation of the project. From there the time to construct and optimise the device had to be made efficient and this is where the group deviated to work in pairs to achieve the tasks in unison. The outcome was that, despite the initial time deficit, there was sufficient time to test the device and proof the validity of the concept.

The following pages are the final Gantt chart for the report.
null
<table>
<thead>
<tr>
<th>Date</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fri 2/10/15</td>
<td>Adrian Di Nardo</td>
<td>Manual Summary Rollup</td>
</tr>
<tr>
<td>Tue 29/09/15</td>
<td>Juliano Paradiso</td>
<td>Fri 9/10/15</td>
</tr>
<tr>
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<td>Adrian Di Nardo</td>
<td>Mon 21/09/15</td>
</tr>
<tr>
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<tr>
<td>Wed 30/09/15</td>
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</tr>
<tr>
<td>Tue 20/10/15</td>
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<td>Tue 20/10/15</td>
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<td>Fri 2/10/15</td>
<td>Adrian Di Nardo</td>
<td>Fri 2/10/15</td>
</tr>
<tr>
<td>Mon 28/09/15</td>
<td>Adrian Di Nardo</td>
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</tr>
<tr>
<td>Date</td>
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</tr>
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<td>Mon 28/09</td>
<td>Chapter 4: Project Specifications</td>
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</tr>
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</tr>
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</tr>
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<td>147</td>
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<td>Voltage, Amperage, Frequency</td>
<td>150</td>
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<tr>
<td>Wed 28/10</td>
<td>Voltage, Amperage, Frequency</td>
<td>147</td>
</tr>
</tbody>
</table>
C: Safe Operating Procedure

SAFE OPERATING PROCEDURE:
1989: Water Treatment Using Non-Thermal Plasma

LOCATION DETAILS
School/Branch: Mechanical Engineering

TASK/ACTIVITY
Final Year Project for Mechanical Engineering
Date: 14 / 9 / 2015

PREPARED BY
Name, Position and Signature (insert names of the supervisor, HSR, HSO and operator involved)

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruben de Vries</td>
<td>Student</td>
<td></td>
</tr>
<tr>
<td>William Leonard</td>
<td>Student</td>
<td></td>
</tr>
<tr>
<td>Juliano Paradiso</td>
<td>Student</td>
<td></td>
</tr>
<tr>
<td>Adrian Di Nardo</td>
<td>Student</td>
<td></td>
</tr>
<tr>
<td>Dr. Erwin Gamboa</td>
<td>Supervisor of Project &amp; Lab</td>
<td></td>
</tr>
</tbody>
</table>

HAZARD IDENTIFICATION:
See Risk Assessment dated 08 / 09 / 2015

RISK ASSESSMENT
2930

SAFE OPERATING PROCEDURE DETAILS

STOP

DO NOT OPERATE PLANT IF YOU HAVE NOT COMPLETED (1) THE COMPULSORY UNIVERSITY OF ADELAIDE OCCUPATIONAL HEALTH AND SAFETY INDUCTION COURSE, AND; (2) DO NOT POSSESS THE REQUISITE QUALIFICATIONS OR TRAINING FOR THIS PIECE OF PLANT.

Preparation – work area check:
- Ready access to and from the device.
- Area is free from grease, oil, liquids, debris and objects, which can be tripped over.
- Area is clear of unauthorised people before commencing work.

Personal Attire & Safety Equipment:
- Approved closed toe type shoes must be worn at all times.
- Safety glasses are to be worn when operating the device.
- Ensure extraction fan is always operational when the device is turned on.

Machine Pre-operational Safety Checks – Safety Precautions that MUST be Observed:
- Ensure all power to the device is disconnected and both the function generator and power supply are turned off.
- Visual inspection of machine to verify it is in good operational order, ensuring no damage or faults (i.e. loose fittings, cracks, exposed wire and loose leads). Any unsafe equipment is to be reported to all group members and project supervisors.
- Ensure all connections are properly secured and configured correctly.
- Ensure lighting and power are switched on their respective main switches, where required.
- Be aware of other activities happening in the immediate area.
- Ensure that no slip and/or trip hazards are present.
SAFE OPERATING PROCEDURE: 1989: Water Treatment Using Non-Thermal Plasma

- Ensure that machine lighting is adequate.
- Check that the Emergency Stop is working if applicable (completed by Erwin on 09/09/15).

**IF IN DOUBT, ASK**

**Operation:**
- Fill the testing container with the required dosage of water and close the lid, ensuring the container is properly sealed.
- Connect power to the function generator and turn the unit on. Ensure the correct settings are selected which includes square wave and desired frequency.
- Connect power to the power supply and only turn unit on however do not start it yet. Engage OCP (Over-Current Protection) and OVP (Over-Voltage Protection) settings.
- Select appropriate frequency on the function generator.
- Select appropriate voltage and amperage on the power supply.
- Perform a final inspection of the system and components before turning the power output on.
- Turn the power output switch on the power supply to the on position.
- Monitor the operation of the system (i.e. fluctuations in voltage/current/frequency, any undesired changes to the system). If any undesired changes occur, turn the power supply off immediately from either the power output switch or by disconnecting power from the power point. If these options are deemed unsafe, use the Emergency Stop.
- After the system has operated for a predetermined time, turn the power output switch to the off position.
- Inspect all equipment for faults and damage.
- Open the container and extract water for analysis.

**General Safety**
- Visual inspection of device prior to use.
- Keep all parts of your body and attire safely clear of the electrical circuits, the anode and cathode.
- Only authorised qualified students and staff to operate this machine.
- Never leave the non-thermal plasma device running whilst unattended.
- Always ensure two group members are present while the device is being operated.
- Closed Toe Type Shoes must be worn during the operation of this machine.
- Rag or cotton waste (eg for cleaning) must not be used near the device.

**Note:** This Safe Operating Procedure must be reviewed:
- a) after any accident, incident or near miss;
- b) when training new staff;
- c) if adopted by new work group;
- d) if equipment, substances or processes change; or
- e) within 1 year of date of issue.
APPENDIX D. BUDGET

D: Budget

Strict time and financial budgets which were imposed by The University of Adelaide, these had to be adhered to for the successful completion of the project. Using the budget structure giving by the university the total for the project came to $153302.37, the breakdown of the budget is as follows:

**Cost Management**  The financial budget of the project was $200.00 per person which equates to a total of $800.00 to purchase all necessary equipment which cannot be supplied by The University of Adelaide. The device construction was the only cost demanding process because the operation of the system is without any consumables.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
<th>Cost</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waveform Generator</td>
<td>1</td>
<td>N/A</td>
<td>University of Adelaide</td>
</tr>
<tr>
<td>Alternative Waveform Generator</td>
<td>1</td>
<td>$26.85</td>
<td>Jaycar</td>
</tr>
<tr>
<td>Power Supply</td>
<td>1</td>
<td>$184.65</td>
<td>Aztronics Enfield</td>
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<tr>
<td>IP65 Electrical Box</td>
<td>1</td>
<td>$36.26</td>
<td>M&amp;M Electrical</td>
</tr>
<tr>
<td>Stainless Steel Rings</td>
<td>1</td>
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</tr>
<tr>
<td>Stainless Steel Bolts (6mm)</td>
<td>1</td>
<td>$3.86</td>
<td>Bunnings</td>
</tr>
<tr>
<td>Stainless Steel Bolts (8mm)</td>
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<td>$20.50</td>
<td>Bunnings</td>
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</table>

**Alternative Design Options**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
<th>Cost</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone Power Supply Kit</td>
<td>1</td>
<td>$200</td>
<td>Aliexpress</td>
</tr>
<tr>
<td>Alternative Electrode Tube</td>
<td>1</td>
<td>$250</td>
<td>Aliexpress</td>
</tr>
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**Miscellaneous**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
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<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium Carry Case</td>
<td>1</td>
<td>$36.32</td>
<td>Aztronics Enfield</td>
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<tr>
<td>IGBT 600V 16A Transistor</td>
<td>1</td>
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</table>

**TOTAL** $771.97

A lot of the budget was spent on developing a device which operates as desired and also is cost effective to the end user. This can be further enhanced by conducting a study of the viability of commercialisation of the system which could introduce the advantages of bulk purchasing and new solutions for more efficient fabrication procedures.

**Workshop Time**  The workshops at The University of Adelaide were available the project for a total of 40 hours per student (160 in total) and this time is to be used for the design, fabrication and optimisation of the final design. Two workshops in The University of Adelaide were available, mechanical and electrical, for the project to use. The electrical workshop was used extensively for the initial build as well as the on going enhancements for the device.

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Time (Hours)</th>
<th>Primary Attendant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>36</td>
<td>Derek Franklin</td>
</tr>
<tr>
<td>Mechanical</td>
<td>1</td>
<td>Garry Clarke</td>
</tr>
</tbody>
</table>

**TOTAL HOURS** 37

**Cost Per Hour** $50

**TOTAL COST** $1850

The total workshop time used was 37 hours, the breakdown is shone in the table above, at a cost of $1850 which is well below the budget and this was achieved by the system requiring minimal fabrication and the efficiency of the workshop staff.
Stakeholders Time  The stakeholders of the project, as previously introduced, are the students (Ruben de Vries, Adrian Di Nardo, William Leonard and Juliano Paradiso) and the supervisors (Dr. Erwin Gamboa and Dr. Cristian Birzer). There were no time constraints implied for the contribution of the students and supervisors apart from the necessity to meet the respective deadlines.

The primary contribution by supervisors were one hour meetings every week or when necessary, drafting and approval of formalities such as reports and safe operating procedures as well as any additional advice necessary during the progression of the project. The student’s time was allocated to complete the project’s goals and to have equal contributions from all involved. This parity is to ensure the students still deserve the same credit for their work on the project. The total time spent by each student is shown below.

<table>
<thead>
<tr>
<th></th>
<th>Ruben de Vries</th>
<th>Adrian Di Nardo</th>
<th>William Leonard</th>
<th>Juliano Paradiso</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total YTD (Hrs)</td>
<td>570</td>
<td>520</td>
<td>560</td>
<td>579</td>
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</table>

Costs YTD

<table>
<thead>
<tr>
<th></th>
<th>Total (Salary)</th>
<th>Total (Direct)</th>
<th>Total (Indirect)</th>
<th>Total Cost</th>
</tr>
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<td></td>
<td>$14,820</td>
<td>$4,446</td>
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<td></td>
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<td>$150,680.4</td>
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</table>

The total cost of the stakeholders time was **$150,680.40** which is based on an individual earning $50,000 per annum. The direct costs are 30% of the salary which allows for superannuation, payroll tax, Work-cover, long-service and general leave. The indirect costs are 130% for costs of the business, such as admin, tech support, infrastructure, rent, phone and internet.
<table>
<thead>
<tr>
<th>Location</th>
<th>The University of Adelaide - Fac of Eng, Comp &amp; Math Sci - School of Mechanical Eng - *N/A - North Terrace - Engineering South - ENS - *N/A - Lab - 1989: Water Treatment Using Non-Thermal Plasma</th>
</tr>
</thead>
<tbody>
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</tr>
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</tr>
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<td>North Terrace</td>
</tr>
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</tr>
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</tbody>
</table>
Rubber gloves to be worn when turning on the power supply. Ensure the water container is fixed close and the device is secured to bench. Ensure all personnel are aware when the device is about to be started. Investigate all leads before starting the device for any defects. Keep the device and work area neat and tidy.

What controls are currently in place?

Risk Assessment Keywords

William Leonard

Medium (12)

When a person comes in contact with high or low voltage electricity. This may occur if the high voltage leads melt, a water leak/spillage while device is live, touching exposed wires/leads, 12V DC power supply earthing through a person due to on/off button being next to the positive terminal.

Is there the potential for a person to come into contact with live electricity or receive an electric shock? Eg Overhead or underground power lines, exposed wires, water near equipment, leads/switch in poor condition

Contact with electricity or potential for electric shock

Assessor

Residual

How can this

Hazard Description/Nature of Risk

Hazard ID

Control Type

Progress

Cost

Person

Due Date

Responsible

Control Statement

Action Description

ID

Printed copies are uncontrolled

Page 2 of 7

(Printed 8 Sep 2015 12:18:31 PM)  Printed copies are uncontrolled
A pulsed DC power source will be used to prevent the plasma from heating up. The over voltage as well as over amperage kill settings on the power supply device will always be selected.

What controls are currently in place?

Risk Assessment Keywords

William Leonard

Low (4)

The temperature of the plasma generated from an electrical arc can become high. The 12V DC power supply can also heat up internally.

Is there the potential for a person to come into contact with an object which is hotter than 50 degrees Celsius? Eg steam, naked flame, laser beams

Contact with hot object or friction burn

14537

Assessor

Residual Hazard Description/Nature of Risk

How can this event be prevented?

Control Type

Progress

Cost

Due Date

Responsible Person

Control Statement

Action Description

ID
Adequate ventilation will be required. Care must be taken when handling the water samples. Use of a level two microbiological lab will be used when testing with E.coli. Hands to be washed after handling materials. Introduction and training from Dr. Connor Thomas in regards to using E.coli.

<table>
<thead>
<tr>
<th>Risk Assessment Keywords</th>
<th>William Leonard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure to biological hazards?</td>
<td>Yes</td>
</tr>
<tr>
<td>Person can produce a biological hazard?</td>
<td>Yes</td>
</tr>
<tr>
<td>Person can be exposed to biological hazard?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard Type</th>
<th>Control Type</th>
<th>Progress</th>
<th>Cost</th>
<th>Due Date</th>
<th>Responsible Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological</td>
<td>Mitigate them completely.</td>
<td>In progress</td>
<td>Nil</td>
<td>60 days</td>
<td>William Leonard</td>
</tr>
</tbody>
</table>

What controls are currently in place?

- Adequate ventilation will be required.
- Hands to be washed after handling materials.
- Use of a level two microbiological lab will be used when testing with E.coli.

Is there the potential for a person to be exposed to biological hazards?

- Yes

How can this residual risk be reduced?

- Educate personnel on proper handling procedures.
Two different locations to turn off the power are available. The power can also be cut from the power points. Ensure the power points are within close reach.

**What controls are currently in place?**

- On/off switch on the power supply
- Power cut from power points

**Risk Assessment Keywords**

- Medium

In case of any emergency where the built-in safety mechanisms fail to shut off the power to the device:

- Does the machinery require an emergency stop button? EG location is within reach, mushroom button

---

<table>
<thead>
<tr>
<th>ID</th>
<th>Hazard Description</th>
<th>Nature of Risk</th>
<th>Control</th>
<th>Control Type</th>
<th>Progress</th>
<th>Person</th>
<th>Cost</th>
<th>Due Date</th>
<th>Responsible Person</th>
<th>Control Statement</th>
<th>Action Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14539</td>
<td>Operation - shut down procedure</td>
<td>In case of any emergency situation</td>
<td>mushroom button</td>
<td>Event</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Does the machinery require an emergency stop?</td>
</tr>
</tbody>
</table>
 Ensure appropriate footwear is worn and stop work until the spillage is cleaned up.

What controls are currently in place?

Risk Assessment Keywords

William Leonard

Low (4)

The system will involve the use of water, therefore if there is any spillage on the ground it may result in slipping over.

Is there the potential for a person to slip, trip or fall?

Slips, trips or falls

14540

Assessor

Residual

Hazard Description/Nature of Risk

Hazard Description

Assessor

How can this be decreased/managed?

Hazard Description/Nature of Risk

Residual

14540

Slips, trips or falls
Only operate in a well-ventilated area, e.g. extraction fan or natural ventilation. Ensure more than one person is present when system is being operated. Check container for leaks regularly and ensure seals are not damaged. Use ozone-safe materials as it is an oxidant.

**Risk Assessment Keywords**

**Environmental hazards**

<table>
<thead>
<tr>
<th>Hazard Description/Nature of Risk</th>
<th>Control Type</th>
<th>Progress</th>
<th>Cost</th>
<th>Due Date</th>
<th>Responsible Person</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**What controls are currently in place?**

- Ozone may cause discomfort on the period of exposure. This may be eliminated by increasing the ventilation.
- Ozone is known to irritate the eyes, nose, throat, and can be a cause of coughing.
- The current, and future emissions, could cause discomfort.
- There is a possibility of generating significant emissions.

**Environmental hazards**

- Medium (12)
- Environmental hazards, E.g. Ozone
- Intermediate case: No Risk
## F: Risk Assessment: Project

### Impact Assessment scale

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Detailed Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Insignificant</td>
<td>Insignificant data lost, low financial loss, minimal delay on project</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>Preventable partial data lost, medium financial loss, a minor halt or setback for the project</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Preventable total data lost, high financial loss, a moderate halt or setback for the project</td>
</tr>
<tr>
<td>4</td>
<td>Major</td>
<td>Unpreventable partial data lost, major financial loss, major delay on project resulting in missed deadlines</td>
</tr>
<tr>
<td>5</td>
<td>Catastrophic</td>
<td>Unpreventable total data lost, high financial loss, an indefinite stop on the project</td>
</tr>
</tbody>
</table>

### Likelihood Assessment Scale

<table>
<thead>
<tr>
<th>Level</th>
<th>Likelihood</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Almost Certain</td>
<td>Occurs routinely and should be expected to occur</td>
</tr>
<tr>
<td>B</td>
<td>Likely</td>
<td>Good chance to occur as it happens often</td>
</tr>
<tr>
<td>C</td>
<td>Moderate</td>
<td>Should occur at some time</td>
</tr>
<tr>
<td>D</td>
<td>Unlikely</td>
<td>Possibly could occur at some time</td>
</tr>
<tr>
<td>E</td>
<td>Rare</td>
<td>In exceptional circumstances may it occur</td>
</tr>
</tbody>
</table>

### Level of Risk

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Insignificant</th>
<th>Minor</th>
<th>Moderate</th>
<th>Major</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Significant</td>
<td>Significant</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>B</td>
<td>Medium</td>
<td>Significant</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>C</td>
<td>Low</td>
<td>Medium</td>
<td>Significant</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>D</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Significant</td>
<td>High</td>
</tr>
<tr>
<td>E</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Significant</td>
<td>Significant</td>
</tr>
</tbody>
</table>

### Level of Risk Key

<table>
<thead>
<tr>
<th>Risk rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Risk</td>
<td>Regular monitoring – risk management strategies (Hierarchy of Control Measures) used are likely to be sufficient to manage the risk</td>
</tr>
<tr>
<td>Medium Risk</td>
<td>Adapt specific risk management strategies, and monitor progress</td>
</tr>
<tr>
<td>Significant Risk</td>
<td>Identify management plan for specific risks, continuous monitoring</td>
</tr>
<tr>
<td>High Risk</td>
<td>Immediate attention and action will be required to manage the unique needs of the risk situation.</td>
</tr>
</tbody>
</table>
## Risk Assessment for Risk Action Plan

<table>
<thead>
<tr>
<th>Risk #</th>
<th>The Risk</th>
<th>Before Risk Action Plan</th>
<th>After Risk Action Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Member Sickness / Unforeseeable circumstances</td>
<td>B 4 High</td>
<td>B 2 Significant</td>
</tr>
<tr>
<td>2</td>
<td>Missed Information</td>
<td>B 4 High</td>
<td>B 3 Significant</td>
</tr>
<tr>
<td>3</td>
<td>Lead Times / Time Constraints</td>
<td>B 4 High</td>
<td>C 3 Medium</td>
</tr>
<tr>
<td>4</td>
<td>Cannot use required pathogens for testing</td>
<td>C 4 High</td>
<td>D 3 Medium</td>
</tr>
<tr>
<td>5</td>
<td>No access to ozone generator for testing</td>
<td>C 4 High</td>
<td>D 3 Medium</td>
</tr>
<tr>
<td>6</td>
<td>Poor data quality</td>
<td>C 4 High</td>
<td>C 3 Significant</td>
</tr>
<tr>
<td>7</td>
<td>Part Compatibility Issues</td>
<td>C 3 Significant</td>
<td>D 2 Medium</td>
</tr>
<tr>
<td>8</td>
<td>Cost increase / No sponsorship</td>
<td>C 2 Medium</td>
<td>D 2 Medium</td>
</tr>
<tr>
<td>9</td>
<td>Under-performance of Device/ Parts</td>
<td>C 3 Significant</td>
<td>D 3 Medium</td>
</tr>
<tr>
<td>10</td>
<td>Breaking of Components</td>
<td>C 3 Significant</td>
<td>D 2 Medium</td>
</tr>
<tr>
<td>11</td>
<td>No access to testing facilities</td>
<td>D 4 Significant</td>
<td>D 3 Medium</td>
</tr>
<tr>
<td>12</td>
<td>Data storage corrupted or lost</td>
<td>C 4 High</td>
<td>D 2 Medium</td>
</tr>
<tr>
<td>13</td>
<td>Oversimplification / Incorrect Modelling</td>
<td>C 4 High</td>
<td>C 3 Significant</td>
</tr>
<tr>
<td>14</td>
<td>Lack of commitment</td>
<td>C 3 Significant</td>
<td>C 2 Medium</td>
</tr>
<tr>
<td>15</td>
<td>Permanent loss of a member</td>
<td>D 4 Significant</td>
<td>D 3 Medium</td>
</tr>
</tbody>
</table>

L=likelihood  
S=severity  
R=Risk
## Risk Action Plan

<table>
<thead>
<tr>
<th>Risk item number</th>
<th>Risk item</th>
<th>Description / effect on project</th>
<th>Risk reduction actions</th>
<th>Reporting &amp; monitoring requirements</th>
</tr>
</thead>
</table>
| 1                | Member Sickness / Unforeseeable circumstances | People can come down with an illness or personal circumstances that prevent them from completing work at any time. This could prevent them from completing required work, attending meetings and possibly delaying completion dates. | • Keep all work if possible on a public drive, e.g. Google Drive.  
• If possible, complete required work at home.  
• Use detailed minutes to keep everyone up to date.  
• If required, re-allocate workloads to cater for the person missing.                                                                                                                                 | If possible, keep in contact with group members on the condition of the circumstances. This includes how long that person will be absent and if they won’t be able to complete their work. Supervisors can be notified if required. |
| 2                | Missed Information                          | This project will be required to diversify itself from other existing ideas. If a published idea has been missed, the project may find itself not being unique and as a result repeating past work. This could lead to copyright and plagiarism issues, as well as having to change the direction or focus of the project. Deadlines and project quality may be also directly affected. | • The literature review will be required to be in-depth with a large collection of reliable sources.  
• Continual research into published ideas throughout the project.  
• Examine each of the published papers to determine if there were any gaps or discrepancies in their work.  
• If any were found have it checked by another group member.  
• Keep ideas and or concepts recorded in a workbook for future reference.  
• Keep a backup niche that can be used to fall back on if required.                                                                 | If issue found, immediately inform group members and request meeting with supervisors to determine its severity.                                                                                     |
<table>
<thead>
<tr>
<th>Risk item number</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk item</strong></td>
<td>Lead Times / Time Constraints</td>
</tr>
<tr>
<td><strong>Description / effect on project</strong></td>
<td>Parts, components, workshop fabrication, testing, part warranty and information gathering may take longer than anticipated which could delay or prevent the project moving forward. As a result, this may affect the set deadlines for deliverables and goals.</td>
</tr>
</tbody>
</table>
| **Risk reduction actions** | • Start organising all testing as soon as possible with the School of Microbiology to ensure access.  
• Start the purchasing or ordering process immediately after when the component has been confirmed to be required.  
• Support local suppliers if possible to reduce or eliminate time on postage.  
• Manufacturing drawings to be completed in an appropriate time frame. This is to be finalised preferably early to decrease the likelihood of being backlogged by the workshop.  
• Have a meeting with the workshop to gain insight of what is involved and the timeframe they believe is required.  
• Allow a safety factor on deadlines to ensure if something arises that wasn’t anticipated it can be rectified.  
• Keep an alternative solution if applicable if the initial option is no longer available or has been discontinued. This may include another supplier or a similar product.  
• Keep purchase dockets and warranty details to decrease the time claims for faulty products take. |
| **Reporting & monitoring requirements** | Notification to all members required. Keep in contact with those associated with the issue to stay informed on its status as well as timeframe. |

<table>
<thead>
<tr>
<th>Risk item number</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk item</strong></td>
<td>Cannot use required pathogens for testing</td>
</tr>
<tr>
<td><strong>Description / effect on project</strong></td>
<td>To test the microorganism inactivation performance of the device, samples of E. coli and Cryptosporidium will be required. If these are not available, the project will not be able to declare its ability to inactivate those microorganisms, therefore resulting in the project being possibly redundant.</td>
</tr>
</tbody>
</table>
| **Risk reduction actions** | • Organise with Dr Connor Thomas from the School of Microbiology to discuss the availability of the pathogens.  
• Search for external suppliers that may help for supplying or testing. A meeting with the university will be required to decide whether this is an acceptable option.  
• Research other possible testing methods that could be used to achieve the same or similar results. |
<p>| <strong>Reporting &amp; monitoring requirements</strong> | All group members will be required to know of this situation. Supervisors should be contacted and a description of the situation explained. Regular updates and focus will be required on this situation by all group members. |</p>
<table>
<thead>
<tr>
<th>Risk item number</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>No access to ozone generator for testing</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>To complete our testing to satisfy the sub-goal 3.4.1 relating to determining ozone requirements. An ozone generator will be required to try and recreate the CT values from the literature review. Without the generator, the project won’t be able to confirm previous published data is accurate for this application.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | - Organise with supervisors and Dr Connor Thomas from the School of Microbiology to discuss the availability of ozone generators at the University.  
- Search for external suppliers that could provide an ozone generator. A meeting with the university will be required to decide whether this is an acceptable option.  
- Research other methods to produce accurate levels of ozone for the purpose of testing. |
| Reporting & monitoring requirements | William and Juliano will be required to monitor this process carefully as they are investigating the ozone section of the project. Other group members will be informed on the situation. Supervisors should be contacted and the situation explained, possible advice may be given to students if possible. Regular updates to all involved will be required. |

<table>
<thead>
<tr>
<th>Risk item number</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Poor data quality</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>If the water test results come back with inconsistent or inconclusive data.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | - Developing a testing apparatus that can keep the experiments constant to reduce the effects or errors.  
- Have the test results confirmed if possible by an unbiased, independent.  
- Acknowledge the results to be correct and understand what the possible reasons were.  
- Keep easy to access record of all the results.  
- Keep all testing conditions constant to reduce the effect of errors. |
<p>| Reporting &amp; monitoring requirements | All group members will be required to know of the results. Supervisors should be contacted and a description of the situation explained. Regular updates on the situation to all group members will be required. |</p>
<table>
<thead>
<tr>
<th>Risk item number</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Part Compatibility Issues</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>If parts that have been purchased or manufactured specifically for a certain purpose do not fit or work as planned. Could lead to a delay in testing and further production of components. This also includes if the water treatment system does not work in the conditions required.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • Before orders or plans are submitted, in-depth research will be required to ensure items will be suitable.  
• Check design specifications to see if another solution or product is available.  
• Check if minor alterations to the design are feasible to accommodate the changes.  
• Delegate workloads in the group so that group members can work on other deliverables until problem is resolved |
| Reporting & monitoring requirements | Continual updates to group members and supervisors if required. Workshop may need to be contacted if issue could be resolved from them. Immediate action may be required but proceed only if safe to do so. |

<table>
<thead>
<tr>
<th>Risk item number</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Cost increase / No sponsorship</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>Prices of parts and components may be higher than first anticipated or increased without notice. This could lead to a strain on the specified budget. Items may not be able to be purchased and could result in systems not performing as desired. Certain parts may be not required after it was purchased and can’t be returned.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • Research the market to make a compromise on price and performance.  
• Make a priority list which includes must haves to optional items.  
• Keep purchase dockets to increase the likelihood of returning a product if not required.  
• If an item breaks and is under warranty, make a claim to prevent having to purchase the same product again.  
• Explore the possibility of potential sponsors if the initial budget is stretched. |
<p>| Reporting &amp; monitoring requirements | Group member responsible for purchasing that item is required to keep informed. If required, he may branch out to other members of the group to provide assistance. All group members will be required to take the budget into considerations throughout the entire project and inform others if potential issues could arise. |</p>
<table>
<thead>
<tr>
<th>Risk item number</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Under-performance of device/ Parts</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>If components are purchased or manufactured and do not perform at the standard required. The constructed prototype is also included. This could lead to extra expenditure and budget pressure. Time delays and possible change in designs.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • Always investigate the specifications and requirements set from the manufacturer on the parts capabilities.  
• Use the literature review to know possible backup plans if required.  
• Carefully examine results from testing to look for explanations for the underperformance.  
• Have a detailed concept design stage that explores various possible solutions.  
• Check whether or not an alternative part can be purchased.  
• Communicate with the workshop to find out if an alteration could be done to either the system or part. |
| Reporting & monitoring requirements | Group members should all be informed to allow for discussion on possible solutions. Workshop and supervisors may be required to be informed. |

<table>
<thead>
<tr>
<th>Risk item number</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Breaking of Components</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>Components of the system will be subjected to testing where parts may be strained, broken or displaying signs of corrosion.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • Conduct a risk assessment for that testing  
• Ensure all fittings are secured  
• Conduct visual and hearing checks while testing  
• Check for vibration  
• Divide into subsystems if applicable to help identify and or isolate any faults.  
• Keep purchase dockets and warranty details to make a warranty claim. |
<p>| Reporting &amp; monitoring requirements | Regular checks before and during testing of the components. If an issue arises, a written statement as well as a photo will be required to examine what and why it occurred. |</p>
<table>
<thead>
<tr>
<th>Risk item number</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Data storage corrupted or lost</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>A majority of all work completed will be completed on a computer or some form of electronic device. Saved files can be deleted, lost, corrupted with all the work completed gone without warning. This could lead to losing all saved work, missing deadlines and requiring to complete tasks over again.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • Keep all work if possible on a public drive, e.g. Google Drive.  
• Backup work in different locations.  
• Save work regularly to minimise the effect if a computer shuts down unexpectedly.  
• Investigate whether data could be recovered through the use of different programs or a professional. |
| Reporting & monitoring requirements | This is up to the individual to ensure they take the appropriate actions to ensure they do not lose their work. If a large amount of work is lost, contact supervisors to help them understand the situation. |

<table>
<thead>
<tr>
<th>Risk item number</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Oversimplification / Incorrect Modelling</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>If the proposed solution was incorrect and or the assumptions made in the model were not appropriate or over simplified the system may not work as expected. Depending on which stage of the project this is discovered will determine the effect it could have. Time, money and possibly submission dates could be under pressure.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • The literature review to cover various solutions to allow the group to understand what backup strategies could be used.  
• Reviewing calculations from other group members.  
• Know the specifications of the equipment and any special requirements they may require.  
• A testing apparatus to be constructed to minimise the possible alterations to the bicycle. |
<p>| Reporting &amp; monitoring requirements | All group members should request that their work to be reviewed. Part specifications should be examined by group member who orders or is responsible for that component or subsystem. |</p>
<table>
<thead>
<tr>
<th>Risk item number</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>No access to testing facilities</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>The project requires the testing of hazardous microorganisms. It is important to have access to specific laboratories that have safety equipment and procedures to deal with them and prevent outbreaks. If not, the project would likely need to outsource all testing.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • Organise with the School of Microbiology to gain access in one of their laboratories.  
• Search for external laboratories around Adelaide where we can conduct the testing.  
• Test for only ozone production and try to extrapolate the information to determine the performance of the system. Change of scope may be required for this. |
| Reporting & monitoring requirements | This will affect all group members and as a result each will be required to find a solution as soon as possible. Direct communication with supervisors will be required for advice and help. |

<table>
<thead>
<tr>
<th>Risk item number</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Lack of commitment</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>Over time group members may become disinterested or workloads for other subjects may increase. This could result in less time being allocated on the project or the work being below an acceptable level.</td>
</tr>
</tbody>
</table>
| Risk reduction actions | • Group members should try to keep everyone involved and help each other where possible.  
• Keep in contact with all members and help motivate.  
• Have informal catch ups that do not have to incorporate work to help with the group dynamics.  
• Everyone do what they say they will so there are no surprises or people left frustrated at others. |
<p>| Reporting &amp; monitoring requirements | Group members should communicate with other group members about their current status of their situations if possible. Understand how group members may feel and try to come to an appropriate solution. Contact supervisors if necessary to help resolve issues as a last resort. |</p>
<table>
<thead>
<tr>
<th>Risk item number</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk item</td>
<td>Permanent loss of a member</td>
</tr>
<tr>
<td>Description / effect on project</td>
<td>One or more group members may leave the project which would result in an increased workload for those remaining. Information, contacts and existing work could be lost. This could potentially make for a large setback or delay and put additional pressure on the remaining group members.</td>
</tr>
<tr>
<td>Risk reduction actions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Keep all members involved and keep a good professional relationship.</td>
</tr>
<tr>
<td></td>
<td>• Look at ways to resolve the issue to try and prevent them leaving</td>
</tr>
<tr>
<td></td>
<td>• Use a workbook to keep record of all thoughts, ideas, concepts and any other relevant information so that the other work members can take off from where that person left.</td>
</tr>
<tr>
<td></td>
<td>• Obtain their workbook as soon as possible to decrease the chance of delays.</td>
</tr>
<tr>
<td></td>
<td>• Always try to keep other group members informed on what you are working on to reduce the time it would take to catch up on what they had done.</td>
</tr>
<tr>
<td></td>
<td>• Look at possible ways the scope can be reduced to ensure the project can still be completed for the amount of people in the group.</td>
</tr>
<tr>
<td></td>
<td>• Make a workload distribution plan once the person has left to allocate additional work for the remaining group members.</td>
</tr>
<tr>
<td>Reporting &amp; monitoring requirements</td>
<td>Immediately inform all remaining group members and supervisors of the person/s departure to assess the situation. Monitor the workload of each member to determine if there was any additional work allocation issues.</td>
</tr>
</tbody>
</table>
## APPENDIX G. RAW DATA

### Water Treatment Using Non-Thermal Plasma

#### G: Raw DATA

<table>
<thead>
<tr>
<th>Voltage (v)</th>
<th>Frequency (Hz)</th>
<th>Exposure Time (min)</th>
<th>Ozone (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 volts</td>
<td>100</td>
<td>1</td>
<td>0.006349206</td>
</tr>
<tr>
<td>30</td>
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</tr>
<tr>
<td>30</td>
<td>300</td>
<td>1</td>
<td>0.103174603</td>
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<tr>
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<td>0.26031746</td>
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<tr>
<td>24 volts</td>
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<td>0.206349206</td>
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<td>0.10952381</td>
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<tr>
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<th>Exposure Time (min)</th>
<th>Ozone (mg/L)</th>
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<tbody>
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Initial testing to find best voltage
Testing to find best frequency
### Testing to find best time

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Frequency (Hz)</th>
<th>Exposure Time (min)</th>
<th>Ozone Produced (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
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<tr>
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<tr>
<td>24</td>
<td>275</td>
<td>3</td>
<td>0.685714286</td>
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</table>

### Testing to see what diff the bubbling made

<table>
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<th>Bubbles?</th>
<th>Time</th>
<th>Ozone Produced (mg/L)</th>
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<td>No</td>
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</table>

### Testing with E.coli

<table>
<thead>
<tr>
<th>Test Samples</th>
<th>Voltage (V)</th>
<th>Frequency (Hz)</th>
<th>(min)</th>
<th>Ozone Produced (mg/L)</th>
<th>Count (cells/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>24</td>
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<td>0</td>
<td>0</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>2</td>
<td>275</td>
<td>2</td>
<td>0.361904762</td>
<td>&lt;1000</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>275</td>
<td>3</td>
<td>0.595238095</td>
<td>&lt;1000</td>
</tr>
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<td>275</td>
<td>3</td>
<td>0.685714286</td>
<td>&lt;1000</td>
</tr>
</tbody>
</table>
Graphs

Figure 11. Graph of ozone concentration against frequency at 24v

Figure 12. A graph to show the effect of adding a bubbling device to mix the batch
Figure 13. Graph of ozone concentration at 275Hz & 24v against contact time

Figure 14. Graph of ozone concentration against frequency to determine the optimum voltage
### H: Meeting Minutes

**Meeting minutes**

**1989. Water purification from kinetic energy**

**Date of Meeting:** Week 1 04 March 2015
**Start time:** 11:00am  **End time:** 12:10pm

**Location:** Cristian Birzer

**Minutes prepared by:** Adrian Di Nardo

**Purpose of meeting:** General Meeting to discuss project

---

### 1. Agenda

- General discussion about the project, and what next

### 2. Attendance at meeting

- **Present:** Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, Erwin Gamboa, Cristian Brizer
- **Apologies:** William Leonard
- **Absent:**

### 3. Review of previous minutes

- Accepted and actions are up to date

### 4. Progress since last meeting

- Student expectations forms were completed

### 5. Current Minutes (Notes, Decisions, Issues)

- Discussed the importance of taking minutes
- Discussed the scope of the project and the target of the charter
- Need to pick a gap for the project to fill and then prove that our project works
  - How will it be proven
  - Take into account how long bacteria measurements take
- **E-coi testing to be used as main tracer**
  - Confirm with lit review that this is the best test for pathogens in water
- **ACTION 1 – ALL** – identify what is possible with kinetic energy
- **ACTION 2 – ALL** – identify the gaps in research that we can focus on
- Testing of water with molecular biology – discuss with Connor Thomas
- Project is about finding a small gap and addressing it not answering all the questions
- **ACTION 3 – ALL** – write paragraph and send it to supervisors about the desired project goals
- **ACTION 4 – ALL** – read four papers to get started on the details/theory of project
- **ACTION 5 – ALL** – Give as detailed as possible charter to supervisors
- Discuss our expectations for the honors project, ie do you want a P,C,D,HD
- **ACTION 6 – Adrian** – send minutes by end of Thursday
### 6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify what is possible with kinetic energy</td>
<td>All</td>
<td>11/03/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>Identify the gaps in research that we can focus on</td>
<td>All</td>
<td>11/03/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>Write paragraph and send it to supervisors about the desired project goals</td>
<td>All</td>
<td>06/03/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>Read four papers to get started on the details/theory of project</td>
<td>All</td>
<td>11/03/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>Give as detailed as possible charter to supervisors</td>
<td>All</td>
<td>11/03/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>Send minutes by end of Thursday</td>
<td>Adrian</td>
<td>05/03/2015</td>
<td>Completed</td>
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</table>

### 8. Next Meeting

- **Date:** 11/03/2015
- **Time:** 11:00am
- **Location:** Erwins office

**Agenda:**
- Apologies
- Review previous minutes
- Actions arising from previous minutes
### Meeting minutes

**1989. Water purification from kinetic energy**

Date of Meeting: Week 2 11 March 2015  
Start time: 11:05am  
End time: 12:15pm  
Location: Erwin Gamboa’s Office  
Minutes prepared by: Juliano Paradiso  
Purpose of meeting: General Meeting to discuss project

### 1. Agenda

- Review minutes from previous meeting
- Discuss SPPA
- Project Charter
- Gantt Chart
- Workshops

### 2. Attendance at meeting

Present: Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa  
Apologies: Cristian Brizer

### 3. Review of previous minutes

Minutes are accepted

### 4. Progress since last meeting

- Paragraph about desired project goals has been completed
- Each student has read four papers on details/theory of the project
- Rough draft of project charter has been completed
5. Current Minutes (Notes, Decisions, Issues)

- Risk assessment is project risk assessment and overall risks to the project if someone is sick. It is a tool to plan if something goes wrong.
- The goals of the project are to find the gaps in other designs and how we are going to work towards improving them. Identify what has been done, analyse and find what is lacking.
- Goals in Project Charter need to be made more specific.
- Goals can be considered as milestones for payment instalments.
- Gaps in existing designs needs to be analysed to include as goals in project charter.
- Design project to Australian Standards.
- Microsoft Project is recommended for the Gantt Chart but the students can choose.
- For the Gantt Chart under Final Report heading, list the FYP Assessment rubric from Student Handbook. Make sure Gantt Chart is labelled.
- Officially not allowed to work on projects at home.

6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Complete and return SPPA form to Erwin ASAP</td>
<td>All</td>
<td>ASAP</td>
<td>In progress</td>
</tr>
<tr>
<td>2. Send draft of Project Charter by Friday (13/03) afternoon</td>
<td>All</td>
<td>13/03/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>3. Populate Grantt Chart with information from Student Handbook, including holidays and exam period. Send by Friday (13/03) afternoon</td>
<td>All</td>
<td>13/03/2015</td>
<td>In progress</td>
</tr>
</tbody>
</table>

8. Next Meeting

Date: 18/03/2015  
Time: 11:00am  
Location: Erwin’s office  
Agenda:  
- Apologies  
- Review previous minutes  
- Actions arising from previous minutes
Meeting minutes 1989. Water purification from kinetic energy

Date of Meeting: Week 3 Day Month Year 18 March 2015
Start time: 11am End time: 12pm

Location: Cristian Birzer's Office
Minutes prepared by: Ruben de Vries
Purpose of meeting: Further discussion of the project

1. Agenda
- Discuss and approve the meetings of the previous meeting
- Discuss the Project charter progress and set new goals
- System Requirements Review
- Review the Gantt Chart
- Discuss a room allocation for the project
- Discuss the Preliminary Design Review

2. Attendance at meeting
Present: Cristian Birzer, Erwin Gamboa, Adrian Di Nardo, Juliano Paradiso, William Leonard, Ruben de Vries
Apologies: None
Absent: None

3. Review of previous minutes
Minutes of 11/3/2015 are accepted

4. Progress since last meeting
- The charter has been drafted and reviewed by Erwin
5. Current Minutes (Notes, Decisions, Issues)

- The Project charter draft was reviewed by Erwin and discussed
  - The phrase “purifying water” will no longer be used, should be replaced by treated water
  - The goal stating 1ppm should be removed and replaced to aim for a specified reduction in E-coli present
  - An additional major risk is the chance that we can’t test for E-Coli, this should be added to the risk section
  - The scope needs refinement to better match the students and supervisor’s expectations
- William introduced the discussion of which country should be targeted.
  - Consideration should be given to culture. E.g. Is collecting water a woman’s role in their society then would it be appropriate to assume she has a bicycle?
- The financial goals of the project were discussed and it was agreed that these should be vague dependant on the target country
- Further readings are an action item to start the preliminary design stage

6. Action Items

<table>
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<th>Action</th>
<th>Assigned to</th>
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<th>Status</th>
</tr>
</thead>
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<td>2. Complete Project Charter by Friday (20/3/2015 afternoon)</td>
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<tr>
<td>3. Research target country</td>
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<td>20/3/2015</td>
<td>In progress</td>
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<tr>
<td>4. Further Literature readings by entire group</td>
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<tr>
<td>5. Contact the workshop staff to arrange a meeting</td>
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## 8. Next Meeting

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<th>11:00am</th>
<th>Location:</th>
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</tr>
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</table>

**Agenda:**
- Final review of the charter before submission on Friday 27/3/2015
- Final review of the Gantt chart before submission on Friday 27/3/2015
- Discuss the timesheets and remind everyone that it should be reviewed at the start of each month
- Discuss the Preliminary design review
- Discuss the Preliminary Design concepts
- Discuss the Preliminary Report Sections
  - Word processing format?
  - Drawing packages?
Meeting minutes 1989. Water purification from kinetic energy

Date of Meeting: Week 4 March 25, 2015
Start time: 11am End time: 12pm
Location: Cristian Birzer’s Office
Minutes prepared by: Adrian Di Nardo
Purpose of meeting: Further discussion of the project

---

## 1. Agenda

- Review of the charter before submission
- Review of the Gantt chart before submission
- Discuss the timesheets and remind everyone that it should be reviewed at the start of each month
- Discuss the Preliminary design review
- Discuss the Preliminary Design concepts
- Discuss the Preliminary Report Sections
  - Word processing format?

## 2. Attendance at meeting

Present: Cristian Birzer, Erwin Gamboa, Adrian Di Nardo, Juliano Paradiso, Ruben de Vries
Apologies: William Leonard
Absent:

## 3. Review of previous minutes

Minutes of 18/3/2015 are accepted

## 4. Progress since last meeting

The charter and Gantt chart had been updated

## 5. Current Minutes (Notes, Decisions, Issues)

- Review of previous minutes found that having the ongoing literature review in the actions was unnecessary
- ACTION – contact workshop staff
- New meeting time set due to clash
  - Meeting at 11am Tuesday
- Discussion of updated charter took place
  - Missing references in the literature review
  - Thin on details about what we are aiming to do i.e. So many litres per day for average family
  - S.M.A.R.T goals table format is too messy and leaves a lot of ambiguity
- Small paragraph or sentence of goal then have dot points with the S.M.A.R.T below discussed what if we build it and it doesn’t reach the standards
- State that it doesn’t meet AS but does do blah blah, which is blah blah or it does meet the indian standards and so on.
The research section of the work breakdown structure should be called the literature review
  - This section also needs much more detail because everything that follows is built off of it

Discussion of the preliminary report
  - The preliminary report is a tool for supervisors to make sure the project is on the right track
  - Aims, world health says blah blah and water is an issue
  - Lit review shows why we’re doing it
  - Based on lit review we state what we are doing
  - Methodology is the most important section, normally people write it last and

Action 1 – have early preliminary designs/concepts for next meeting

### 6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have early preliminary designs/concepts for next meeting</td>
<td>All Students</td>
<td>31-march-2015</td>
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### 8. Next Meeting

**Date:**

<table>
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**Time:**

<table>
<thead>
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**Location:**

<table>
<thead>
<tr>
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**Agenda:**

- Apologies
- Review previous minutes
- Actions arising from previous minutes
## 1. Agenda
- Review minutes from previous meeting
- Discuss project design with workshop staff
- Discuss Preliminary Design Review

## 2. Attendance at meeting
**Present:** Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa, Cristian Birzer, Garry Clarke, Scott Letton

**Apologies:**

**Absent:**

## 3. Review of previous minutes
Minutes of 25/3/2015 are accepted

## 4. Progress since last meeting
- Background investigation of possible water treatment methods
- Preliminary concept designs

## 5. Current Minutes (Notes, Decisions, Issues)
- Discussed the possibility of making the system as a detachable bicycle trailer. A trailer may increase the overall cost of the system.
- Plasma treatment may be a plausible solution. The kinetic energy can be used to charge a capacitor to produce plasma.
- It may be hard to find data relating pathogen deaths to number of plasma discharges.
- Plasma treatment may raise safety issues with water and high voltage electricity.
- Reverse osmosis may be another water treatment option to investigate.
- Graphene may be another option, however it may not be cost effective.
- Phil Schmidt can be contacted about making a cheap capacitor for plasma treatment.
- A preliminary system can be made from clear acrylic, standard PVC fittings and an irrigation solenoid valve to control the flow rate. A variable speed drive can be used to test the system.
6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>1. Investigate reverse osmosis, plasma, membrane filters, and pulsed electrical discharge.</td>
<td>All</td>
<td>08/04/2015</td>
<td>In progress</td>
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8. Next Meeting

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<tr>
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<th>Location:</th>
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</thead>
<tbody>
<tr>
<td>08/04/2015</td>
<td>11:00am</td>
<td>Erwin’s office</td>
</tr>
</tbody>
</table>

Agenda:
- Apologies
- Review previous minutes
- Discuss investigated water treatment methods
- Meeting with Connor Thomas
- Create actions for the holidays
5. Current Minutes (Notes, Decisions, Issues)

- Review of previous minutes and they were accepted
- Discussed meeting with Dr Connor Thomas
- Reviewed Gantt Chart
- ACTION 1– The Gantt Chart needs to be more detail
  - The water treatment systems is to general, needs sub-points and more like a testing procedure e.g:
  - Test crank to see water moving.
  - All connections are fitted.
  - Test the mechanism for a certain period of time.
- ACTION 2– Gantt Chart, update completion duration of analyse data to two days.
- ACTION 3– Gantt Chart, need to include testing apparatus to the Gantt Chart.
- ACTION 4– All Gantt Chart updates are to be completed by Friday 10th April.
- ACTION 5– Preliminary testing of all components by end of the holidays to determine feasibility of system working.
- Reviewed the preliminary report and discussed its importance to the project.
- Discussed implications of using different technologies and whether the scope of the project needs to be changed from producing safe drinkable water to improving the quality of water.
- Discussed the use of membrane filters, reverse osmosis, plasma and their benefits as well as disadvantages for this project
- ACTION 6– Write Cris a one page review on the initial findings of the water treatment technologies and the possible direction that the project could take.

6. Action Items

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<tr>
<td>1,2,3,4</td>
<td>All Students</td>
<td>10-April-2015</td>
<td>To be completed</td>
</tr>
<tr>
<td>5</td>
<td>All Students</td>
<td>27-April-2015</td>
<td>To be completed</td>
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<td>6</td>
<td>All Students</td>
<td>8-April-2015</td>
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8. Next Meeting

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<th>Location:</th>
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<tbody>
<tr>
<td>15-04-2015</td>
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<table>
<thead>
<tr>
<th>Agenda:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apologies</td>
</tr>
<tr>
<td>Review previous minutes</td>
</tr>
<tr>
<td>Review updated Gantt Chart</td>
</tr>
<tr>
<td>Discuss scope of project and the water treatment method/s that will be used.</td>
</tr>
<tr>
<td>Review plans for preliminary testing of components</td>
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</table>
Meeting minutes 1989. Water purification from kinetic energy

Date of Meeting: Week N/A 15 April 2015 Start time: 11 am End time: 12 pm
Location: Project Room
Minutes prepared by: Ruben de Vries
Purpose of meeting: Discussion about Plasma

1. Agenda
- Discuss journal papers
- Review current status of knowledge about plasma
- Discuss logistics of assembly water filtration test apparatus

2. Attendance at meeting
Present: Adrian Di Nardo, Juliano Paradiso, William Leonard, Ruben de Vries
Apologies: Erwin Gamboa, Cristian Birzer
Absent: None

3. Review of previous minutes
Review of previous meeting minutes will be postponed till next meeting

4. Progress since last meeting
- More journal papers about plasma have been reviewed
- Further developments of testing rig design
5. Current Minutes (Notes, Decisions, Issues)

- The 8 journal papers read by each member was discussed
  o All research into plasma showed good promise of achieving the desired log reduction with all students finding peer reviewed journal papers which show results of at least 3 log reductions
  o An alternative spark generator to the spark plug was introduced, the van de graaf generator. The research shows promising results in other case studies, this will be further researched before next meeting. The only issue which was dicussed was reliability which could be a major drawback
- The electrical components of the test apparatus were discussed
  o An issue which requires research is the accurate measurement of voltage and current created in the spark to determine the consistency of the electrical discharge
  o Further discussions with Phil Schmidt about electrical safety during testing and operation
- The logistics of assembly water filtration test apparatus was discussed
  o All testing with E-coli must be done in the biology labs, access provided by Connor thomas. However initial testing before the end of holidays will not be conducted with E-coli.
  o Initial testing will be conducted using clean water to test the equipment and later it will moved to the biology labs to test the effectiveness of the filtration system.
- An action was introduced for each student to sketch 3 feasible concepts of the entire system and will be shared and discussed via Facebook by 5pm Friday with the intention of discussing these in further detail at next meeting
- The preliminary report is fast approaching and an introduced action item is to have the skeleton ready for the next meeting

6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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<tbody>
<tr>
<td>3 feasible designs from each team member</td>
<td>All students</td>
<td>17/4</td>
<td>In Progress</td>
</tr>
<tr>
<td>Preliminary report Skeleton</td>
<td>All students</td>
<td></td>
<td>On-going</td>
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<tr>
<td>Investigate the use of van de graaf generators</td>
<td>All Students</td>
<td>17/4</td>
<td>In progress</td>
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8. Next Meeting

Date: (DD/MM/YYYY) 20/4/2015  
Time: 11 am  
Location: Erwins Office

Agenda:
- Review previous minutes
- Discuss further plasma technology review
- Review the 3 feasible designs from each team member
- Discuss the location for testing
- Discuss the Preliminary report skeleton
**Meeting minutes**

**1989. Water purification from kinetic energy**

<table>
<thead>
<tr>
<th>Date of Meeting:</th>
<th>Week 2 Mid semester break</th>
<th>20 April 2015</th>
<th>Start time: 11 am</th>
<th>End time: 12 pm</th>
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<tr>
<td>Location:</td>
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<tr>
<td>Minutes prepared by:</td>
<td>Adrian Di Nardo</td>
<td></td>
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**Purpose of meeting:**

1. **Agenda**
   - Review previous minutes
   - Discuss further plasma technology review
   - Review the 3 feasible designs from each team member
   - Discuss the location for testing
   - Discuss the Preliminary report skeleton

2. **Attendance at meeting**
   - Present: Adrian Di Nardo, Juliano Paradiso, Ruben de Vries, Cristian Birzer
   - Apologies: Erwin Gamboa, William Leonard
   - Absent: None

3. **Review of previous minutes**
   - Previous meeting minutes are accepted

4. **Progress since last meeting**
   - More journal papers about plasma have been reviewed
   - Further developments of testing rig design

5. **Current Minutes (Notes, Decisions, Issues)**
   - Discussed that plasma would not be able to remove physical contaminants from the water
   - Cris suggested to look into millbank filters
   - Discussion about the preliminary report, Cris stated he would be happy to review sections of the report at a time and to look at the solar water treatment report from a few years ago an use it as a template
   - Working backwards from the final goal may be easier ie.
     - Figure out the amount of water required per time
     - Find the amount of ozone is needed for that amount of water
     - Find how much plasma is needed to create that amount of ozone
     - Create a circuit to produce that amount of plasma
   - Do the design process learnt in esdc (need > specification > ….)
   - Have further discussion with Phil about how to build a plasma generator
Meeting minutes 1989. Water purification from kinetic energy

- Workout the key variable in the ozone production, is it the voltage or amperage or time of spark
- Break the project down into smaller steps possibly the same structure at the working backwards, discussed above
- If literature doesn’t exist for ozone is needed for that amount of water and how much plasma is needed to create that amount of ozone, then we may need to research it ourselves by:
  o Possibly getting a tank of ozone and test how much is needed to kill e coli
  o Then create a plasma generator and see how much ozone is created per spark
- Action 1: Research how to measure ozone
- Action 2: ask Connor Thomas and Ken Davey (School of Chemical Engineering) if they have a way of measuring ozone

<table>
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<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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<tbody>
<tr>
<td>Research how to measure ozone</td>
<td>Everyone</td>
<td>29/4</td>
<td>TBC</td>
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<tr>
<td>Ask Connor Thomas and Ken Davey (School of Chemical Engineering) if they have a way of measuring ozone</td>
<td>Everyone</td>
<td>29/4</td>
<td>TBC</td>
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8. Next Meeting

Date: (DD/MM/YYYY) 29/4/2015  Time: 12 pm  Location: Erwins Office

Agenda:
- Review previous minutes
- Discuss further plasma technology review
- Discuss the Preliminary report skeleton
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<th>Week N/A 29 April 2015</th>
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<tr>
<td>Minutes prepared by:</td>
<td>William Leonard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purpose of meeting:</td>
<td>Discuss progress</td>
<td></td>
<td></td>
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### 1. Agenda
- Review previous minutes
- Discuss further plasma technology review
- Discuss further ozone research
- Discuss the Preliminary report

### 2. Attendance at meeting
Present: Adrian Di Nardo, Juliano Paradiso, Ruben de Vries, William Leonard, Erwin Gamboa
Apologies: Cristian Birzer
Absent: None

### 3. Review of previous minutes
Previous meeting minutes are accepted

### 4. Progress since last meeting
- More journal papers about plasma and ozone have been reviewed
- The group has selected two people to research either ozone, plasma, pre-treatment and flow control.

### 5. Current Minutes (Notes, Decisions, Issues)
- Discussed ozone and that it is not feasible to store.
- Reviewed direction from questions presented about ozone and plasma.
- ACTION 1: look into materials for tank that won’t fail from the exposure to ozone e.g. clear plastics.
- Discussed making modular designs for each section to improve the quality of testing and obtaining results.
- Discussed how ozone can be dangerous and that it can damage materials.
- Discussed how the project is running one to two weeks behind schedule.
- If required, Erwin has a flume hood we can use when testing.
- ACTION 2: have questions answered with design requirements to start prepare initial construction.
6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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<tbody>
<tr>
<td>Research materials for tank</td>
<td>Everyone</td>
<td>13/5</td>
<td>TBC</td>
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<tr>
<td>Answer questions established for plasma and ozone</td>
<td>Everyone</td>
<td>6/5</td>
<td>TBC</td>
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<tr>
<td>and ozone with design requirements</td>
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8. Next Meeting

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<tbody>
<tr>
<td>6/5/2015</td>
<td>11 am</td>
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Agenda:
- Review previous minutes
- Discuss research on plasma and ozone with questions answered
- Discuss the Preliminary report
# Meeting minutes

**1989. Water purification from kinetic energy**

---

**Date of Meeting:** Week 8  6 May 2015  
**Start time:** 11:05am  
**End time:** 12:00pm  
**Location:** Cris’ Office  
**Minutes prepared by:** Juliano Paradiso  
**Purpose of meeting:** Discuss progress

## 1. Agenda

- Review minutes from previous meeting
- Discuss research on plasma and ozone
- Discuss Preliminary Report

## 2. Attendance at meeting

**Present:** Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Cristian Birzer  
**Apologies:** Erwin Gamboa  
**Absent:**

## 3. Review of previous minutes

Previous meeting minutes are accepted

## 4. Progress since last meeting

- Developed a list of key design requirements for ozone and plasma
- Researched potential suitable materials for use with ozone
5. Current Minutes (Notes, Decisions, Issues)

- Discussed findings from peer reviewed journal article ‘The Impacts of New CT Requirements for Designing Ozone Systems for Cryptosporidium Inactivation’ by Schulz et al. 2005. A 2-log Cryptosporidium ozone disinfection goal can be met with a dose of 4.5mg/L. The article also provides a table of data relating a log reduction to the temperature of the water.
- Electrostatic precipitators may be of use.
- ACTION 1: Investigate the chemical process of ozone to kill pathogens.
- ACTION 2: Investigate how easy different materials are to obtain and apply to our need.
- Testing is required if no further information can be found relating plasma characteristics to ozone generation. May also need to test with various plasma generation methods.
- May be able to use the plasma generator (DBD) at uni but will need to contact Maziar.
- Look at sourcing a suitable ozone meter.
- It will be helpful to research pathogen levels in various waterways throughout the world.
- Photocopiers may be of use for ozone generation.
- Preliminary Report: Aims of the project should go after the literature review to summarise the gaps in the review. Project Management should be laid out as ‘Where you are meant to be’, ‘Where you are’ and ‘What you are going to change’.

6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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<tr>
<td>1. Investigate the chemical process of ozone to kill pathogens.</td>
<td>Juliano, Will</td>
<td>13/05/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>2. Investigate how easy different materials are to obtain and apply to our need.</td>
<td>All</td>
<td>13/05/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>3. Investigate the relationship between plasma and amount of ozone produced.</td>
<td>Adrian, Ruben</td>
<td>13/05/2015</td>
<td>In progress</td>
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8. Next Meeting

Date: (DD/MM/YYYY) 13/05/2015  
Time: 11:00am  
Location: Erwin’s office

Agenda:
- Apologies
- Review previous minutes
- Discuss action items
- Discuss draft of Preliminary Report
### Meeting minutes 1989. Water purification from kinetic energy

<table>
<thead>
<tr>
<th>Date of Meeting:</th>
<th>Week 8 6/11 May 2015</th>
<th>Start time: 11:05am</th>
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<tr>
<td>Minutes prepared by:</td>
<td>Ruben de Vries</td>
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<tr>
<td>Purpose of meeting:</td>
<td>Discuss progress</td>
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1. **Agenda**

- Review previous minutes
- Discuss action items
- Discuss draft of Preliminary Report

2. **Attendance at meeting**

   **Present:** Adrian Di Nardo, Ruben de Vries, Juliano Paradiso, William Leonard, Erwin Gamboa

   **Apologies:** Cristian Birzer

   **Absent:**

3. **Review of previous minutes**

   Previous meeting minutes are accepted

4. **Progress since last meeting**

   - Ozone resistant materials will need to be used for testing and the final product
   - Further developments in correlating ozone production to plasma
5. Current Minutes (Notes, Decisions, Issues)

- How ozone kills bacteria (chemically) was discussed and it was concluded that the details are not relevant to the report.
- Possible ozone resistant materials were discussed with Teflon and polycarbonate recommended by the student; Erwin suggested using TFP.
- DECISION: Testing Ozone/Pathogen Destruction will be necessary to reproduce the results from Schulz et al. as per last meeting (6th May 2015) because the testing time is believed to be minimal.
  - The testing will involve the use of Ecoli and Ozone, therefore it should be conducted in Connor Thomas’s lab.
  - A company by the name, Air Liquide may be useful in acquiring Ozone or an Ozone generator and in addition, Ruben will contact Andrew Young from Key Pool Equipment.
  - The conditions should be predetermined and controlled.
  - ACTION: Determine the equipment required, conditions for testing, health and safety requirements and any paperwork required by the University and Connor Thomas.
- ACTION: Before next meeting, a bench model should be initiated.
- Information has been found correlating plasma generation to discharge gap and environmental conditions however the plasma work is limited in available resources and is starting to affect progress. An extra week has been given for further knowledge collection.
- ACTION: Further research into plasma to determine the plasma generation system.
- The preliminary report draft so far was discussed with Erwin giving guidance on his expectations of the report.
- ACTION: Complete the draft of the preliminary report by next meeting.

6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>Determine the equipment required, conditions for testing, health and safety requirements and any paperwork required by the University and Connor Thomas</td>
<td>All Students</td>
<td>On-going</td>
<td></td>
</tr>
<tr>
<td>Initiate the building of a bench model once action 1 is complete</td>
<td>All students</td>
<td>On-going</td>
<td></td>
</tr>
<tr>
<td>Further research into plasma to determine the plasma generation system</td>
<td>Ruben, Adrian</td>
<td>20/5/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>Complete the draft of the preliminary report</td>
<td>All Students</td>
<td>20/5/2015</td>
<td>In progress</td>
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8. Next Meeting

<table>
<thead>
<tr>
<th>Date: (DD/MM/YYYY)</th>
<th>28/07/2015</th>
<th>Time: 1:00 pm</th>
<th>Location: Erwin's office</th>
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**Agenda:**
- Review previous minutes
- Discuss action items
- Discuss result of Preliminary Report
- Discuss Progress of Project
- Create future action items
- Discuss new Semester 2 meeting time (1pm on Tuesdays)
Meeting minutes

1989. Water purification from kinetic energy

Date of Meeting: 30 July 2015  
Start time: 11:10am  
End time: 12:00pm

Location: Erwin’s Office

Minutes prepared by: Juliano Paradiso

Purpose of meeting: Discuss Preliminary Report and progress of project

1. Agenda
   - Review minutes from previous meeting
   - Discuss Preliminary Report
   - Discuss progress of the project

2. Attendance at meeting
   Present: Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa
   Apologies: Cris Birzer
   Absent:

3. Review of previous minutes
   Minutes of 13/5/2015 are accepted

4. Progress since last meeting
   - A basic prototype system has been constructed and is producing an arc.
   - Preliminary report completed.

5. Current Minutes (Notes, Decisions, Issues)
   - Overview of comments from the preliminary report. Content and writing style gave the impression of ‘trust us, we know what we’re doing’. Actual figures and values for the system to achieve were vague or missing. It may be better to find standards for values such as log reductions and say ‘if we meet this standard, our system has succeeded’.
   - The project is at least one month behind in schedule.
   - ACTION: Create a roadmap – Where are we? Where do we want to be? How are we going to get there? Any critical paths that need to be completed for further progress of the project.
   - Testing will require a comprehensive risk assessment and safe operating procedure (SOP).
   - The corrosion lab is a potential area that can be used to test the operation of the system without any pathogens involved. This lab has power and an extraction fan.
### 6. Action Items

<table>
<thead>
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<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>1. Create roadmap</td>
<td>All</td>
<td>04/08/2015</td>
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</tbody>
</table>

### 8. Next Meeting

- Date: (DD/MM/YYYY) 04/08/2015
- Time: 1:00pm
- Location: Erwin’s office

**Agenda:**
- Apologies
- Review previous minutes
- Discuss roadmap
**Meeting minutes 1989. Water purification from kinetic energy**

**Date of Meeting:** 4 August 2015  
**Start time:** 1:10 pm  
**End time:** 2:00pm

**Location:** Erwin’s Office  
**Minutes prepared by:** Adrian Di Nardo  
**Purpose of meeting:** Discuss the roadmap and progress of project

## 1. Agenda

- Review minutes from previous meeting  
- Discuss the roadmap

## 2. Attendance at meeting

**Present:** Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa  
**Apologies:** Cris Birzer  
**Absent:**

## 3. Review of previous minutes

Minutes of 30th of July 2015 are accepted, but were to brief

## 4. Progress since last meeting

- Work on the basic prototype system has been constructed and is now producing an arc near water  
- Road map created

## 5. Current Minutes (Notes, Decisions, Issues)

- Showed Erwin the roadmap/project management sheet that was created  
- The roadmap has the level of detail that original Gantt chart should have had  
- Some dates on the roadmap have been automatically changed to USA format creating confusion, in future need to double check before printing  
- The planning is good but work needs to start to be done  
- The dates seem optimistic, but that is not an issue as it means that there will be some wriggle room  
- Turning the roadmap into a Gantt chart may be beneficial  
  - It could help ensure that nothing is missed creating issues in the future  
- Creating consequences for failing deadlines is ok, but the consequences cannot be to sever such that it creates the situation where the work being done is rushed to meet the deadlines rather than to the best standard possible.  
- Talked about the abstract for mech expo as it is due in two weeks,  
  - The abstract only needs to be half a page to a page  
  - Look a previous years to gain a perspective on what needs to be done
Meeting minutes 1989. Water purification
from kinetic energy

- Should not dwell on it too much as most of it can be copied from past work
- Erwin would like to see a copy of it
- Discussed how the group intends to create additional roadmaps/project management sheets as new tasks are created and for the deliverables of the project such as the final report
- The group went to meet with Dr Connor Thomas to initiate the testing process
  - Was informed that Dr Connor Thomas has retired, but still comes into university for three days each week
  - A group member will need to meet with him on one of those days to see if he is still willing to help the project
  - School of molecular biology reception gave the name of another person who may be of help
  - Erwin suggested that we meet with the new person in the meantime, to mitigate the risk
- The designs of our device are not necessary for the final report as the project is focused on filling the gap, not on creating a prototype to help fill the gap
  - We need to specify in the final report that we are not trying to create a final system that can be implemented
  - Electrical workshop may want designs to ensure that the device is safe

6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meet with Dr Connor Thomas</td>
<td>Juliano</td>
<td>10/08/2015</td>
<td>In progress</td>
</tr>
<tr>
<td>Meet with new person</td>
<td>Juliano</td>
<td>10/08/2015</td>
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<tr>
<td>Complete tasks on roadmap</td>
<td>All</td>
<td>As the roadmap states</td>
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</tbody>
</table>

8. Next Meeting

Date: (DD/MM/YYYY) 11/08/2015  Time: 1:00pm  Location: Erwin’s office

- Apologies
- Review previous minutes
- Discuss work completed since last meeting
- Discuss meetings with Dr Connor Thomas and new person
- See if the roadmap goals and dates are being achieved
### Meeting minutes

**1989. Water treatment using non-thermal plasma**

**Date of Meeting:** 11 August 2015  
**Start time:** 1:10 pm  
**End time:** 2:00 pm

**Location:** Erwin’s Office  
**Minutes prepared by:** William Leonard

**Purpose of meeting:** Update on progress made and discuss any developments made throughout the week.

### 1. Agenda

- Review minutes from previous meeting
- Discuss work completed since last meeting
- Discuss meetings with Dr Connor Thomas and new person
- See if the roadmap goals and dates are being achieved

### 2. Attendance at meeting

**Present:** Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa

**Apologies:** Cris Birzer

**Absent:**

### 3. Review of previous minutes

Minutes of 4th of August 2015 were accepted.

### 4. Progress since last meeting

- Investigation into plasma generation and key design specifications was completed
- Abstract draft was completed
- Sourced a possible ozone generator for testing

### 5. Current Minutes (Notes, Decisions, Issues)

- Reviewed abstract for MechExpo and comments made were:
  - To reword second paragraph as it needs to be cohesive.
  - Another sentence or two required on what the gap exactly is.
  - The abstract is about where it needs to be.
- Discussed the ozone generator, this included:
  - How it works, this involved explaining setups of the system to see if suitable.
  - The costs which were:
    - $110/week plus $75 for non-reusable parts
    - $589 outright
  - A deposit of the outright price is required and will be refunded when returned.
  - Discussed if testing with an ozone generator would be worth doing as we are unable
Meeting minutes  1989. Water treatment using non-thermal plasma

Page 2 of 2

to measure the ozone directly.
• After a discussion, the consensus was to continue with the ozone generator to establish the link between ozone and pathogen destruction. This way we can minimise testing with our device and pathogens later on.
• Discussed if the goals are still being achieved.
  • Erwin pointed out that things are starting to slip due to waiting for people to get in contact with us. However, this can be made up.
• The SOP & Risk Assessment are the same for the device and testing as they both need to be in high detail. However, we still need to clarify this with Dr Connor Thomas.
• Discussed changing the name of the group to reflect the project better.
  • ‘Water treatment using non-thermal plasma’ is the new name.
• Discussed change in meeting time for the following week due to Erwin being away.
  • Next meeting will be held on the 20/08/2015.

6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>Meet with Dr Connor Thomas and other related personal to organise testing</td>
<td>Juliano</td>
<td>14/08/2015</td>
<td>In progress</td>
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<tr>
<td>Complete tasks on roadmap</td>
<td>All</td>
<td>As the roadmap states</td>
<td>In progress</td>
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<tr>
<td>MechExpo Abstract 2nd paragraph needs fixing to explain the gap better</td>
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8. Next Meeting

Date: (DD/MM/YYYY)  20/08/2015  Time:  1:00pm  Location:  Erwin’s office

Agenda:
• Apologies
• Review previous minutes
• Discuss work completed since last meeting
• Discuss meetings with Dr Connor Thomas and Dr Min Kwan Kim
• See if the roadmap goals and dates are being achieved
Meeting minutes  

**1989. Water treatment using non-thermal plasma**

---

**Date of Meeting:** 20 August 2015  
**Start time:** 1:10 pm  
**End time:** 2:00 pm

**Location:** Erwin’s Office  
**Minutes prepared by:** Ruben de Vries  
**Purpose of meeting:** Update on progress made and discuss any developments made throughout the week.

### 1. Agenda

- Apologies
- Review previous minutes
- Discuss work completed since last meeting
- Discuss meetings with Dr Connor Thomas and Dr Min Kwan Kim
- See if the roadmap goals and dates are being achieved

### 2. Attendance at meeting

**Present:** Ruben de Vries, Juliano Paradiso, William Leonard, Erwin Gamboa

**Apologies:** Cris Birzer, Adrian Di Nardo

**Absent:**

### 3. Review of previous minutes

Minutes of 11th of August 2015 were accepted.

### 4. Progress since last meeting

- Communications maintained with Connor Thomas
- Testing with ozone generator has been cancelled
- Ingenuity Abstract has been completed and approved by both supervisors
- Initial design concepts for the plasma device have been produced

### 5. Current Minutes (Notes, Decisions, Issues)

- The previous meeting minutes were accepted
  - Erwin commented that care should be taken with spelling mistakes
- The roadmap of the project was reviewed
  - General Comment: The project is still running behind but it is clear we are starting to catch up
  - Most of the work for the week will be to meet the deadline of building the plasma device by Monday, 24th August
    - This work includes creating conceptual and final design drawings, sourcing and building the device
    - Work is also continuing on sourcing all the parts necessary for testing the plasma device
  - Meetings took place with Dr. Connor Thomas, Dr. Min Kwan Kim and People from Schneider Electric
Meeting minutes  1989. Water treatment using non-thermal plasma

- Dr. Connor Thomas met with the entire team to discuss the biological testing, minutes have been published for this.
- Meeting with Dr. Min Kwan Kim: It was discovered that there is a similar project which is run by Dr. Min Kwan Kim however their project was found to more focus on the build and optimisation of the plasma device. It was the consensus from both co-ordinators that the projects can run in parallel without any issues
- Ruben met with a contact at Schneider Electric (Steve Clapperton) and the following was discussed:
  - The current conceptual design is to use a 12V power source, Frequency generator and a car coil, this was discussed and in their opinion it is applicable to this case
  - Their advice is that the high voltage needs to be carefully handled to ensure safety is maintained
  - They are more than happy to contribute with equipment and/or technical advice
  - After the meeting, a brief was created to distribute to their contacts that may have previously done research in the area but there has been no response since
- Communications with Laboratory and Safety Co-ordinator of Chem. Eng., Dr. Sanaz Orandi for the following matters:
  - There is no glassware available in Molecular, use equipment from the Chemical Engineering Labs.
  - She is not aware of any ozone measurement techniques available at the university apart from using the Indigo Trisulphonate. This technique has also been used and recommended by Post Grad, Stephen Amos.
- Before testing can occur, some of us will need to complete biological training with Dr. Connor Thomas
- The progress of building the device is currently going well with most of the necessary equipment due to arrive by Friday, 21 August or Monday, 24th August
  - The electronics lab has been very busy but a meeting is scheduled directly after this meeting to discuss the validity of the design and more information on sourcing equipment available from the university i.e. Function Generator & 12V DC Power Supply
  - The Project seems to have “bottle necked”, the whole group seems to be waiting on Ruben to build and document the device. This poses a serious risk to the project and without due care & continuous monitoring can make the project fall further behind.
  - The group is to meet after this meeting to better distribute the work and enhance communication
Meeting minutes 1989. Water treatment using non-thermal plasma

6. Action Items

<table>
<thead>
<tr>
<th>Action</th>
<th>Assigned to</th>
<th>Due Date</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>Meet with electronics lab about design</td>
<td>Ruben de Vries</td>
<td>21/8/2015</td>
<td>In Progress</td>
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<tr>
<td>Finalise design &amp; build of plasma device</td>
<td>Adrian &amp; Ruben</td>
<td>24/8/2015</td>
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<tr>
<td>Complete roadmap tasks</td>
<td>Everyone</td>
<td>Dependent on tasks</td>
<td>On-going</td>
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8. Next Meeting

Date: 20/08/2015  Time: 1:00pm  Location: Erwin’s office

Agenda:
- Review previous minutes
- Discuss work completed since last meeting
- Discuss the build progress of the plasma device
- See if the roadmap goals and dates are being achieved
Meeting minutes 1989. Water purification from kinetic energy

Date of Meeting: 25 August 2015
Start time: 1:00pm
End time: 1:45pm

Location: Erwin’s Office

Minutes prepared by: Juliano Paradiso

Purpose of meeting: Discuss work completed since last meeting and progress of the system build.

1. Agenda
- Review minutes from previous meeting
- Discuss work completed since last meeting
- Discuss the build progress of the plasma device
- See if the roadmap goals and dates are being achieved

2. Attendance at meeting
Present: Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa
Apologies: Cris Birzer
Absent: -

3. Review of previous minutes
Minutes of 20/8/2015 are not accepted as they need to be updated with more information, specifically regarding the need to redistribute bottlenecks in the project (It has been left to Ruben to source parts and build the device).

4. Progress since last meeting
- Most of the componentry required for the new device has been acquired.
- Basic structure of final report has been created.
5. Current Minutes (Notes, Decisions, Issues)

- The roadmap (list of goals and dates to have them achieved by) does not need further revision. The most important goal to complete ASAP is assembling the device.
- ACTION: Complete device assembly.
- Ruben has written a document explaining the components required and how they will be assembled. The document is helpful for giving a basic understanding of the components but may need to be expanded for the final report.
- Ruben had a meeting with the Electrical Workshop, and they confirmed that our device would be okay to build. The workshop has lent us some equipment (waveform generator, MOSFET, other necessary wiring).
- Some components are still yet to be acquired (12V DC power supply, electrodes, and a container for water).
- Copper or stainless steel are potentially suitable materials for the electrodes, however we are unsure whether they will experience any fouling. Erwin suggested that stainless steel may but it will likely be minimal. Erwin also suggested trialing with stainless steel first.
- Dr Min Kwan has previously suggested avoiding using electrodes with pointed edges as electricity will concentrate to these points. Initial ideas were to drill and tap a stainless steel ball bearing and attach it to a bolt. Erwin suggested it may be easier to just round the tip of a bolt instead.
- It is likely that the water will need ions to conduct the electricity properly. Erwin suggested adding sodium chloride to achieve this.
- Review of the Final Report layout. The layout looks okay and is a good start. The report should be written as though the group has already selected non-thermal plasma as the direction of the project rather than providing an extensive background of different water treatment processes.

6. Action Items

<table>
<thead>
<tr>
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<td>1. Complete device assembly</td>
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8. Next Meeting

Date: (DD/MM/YYYY) 01/09/2015  
Time: 1:00pm  
Location: Erwin’s office  
Agenda:  
- Apologies  
- Review previous minutes  
- Discuss progress with device build and testing
**Meeting minutes** 1989. Water purification from kinetic energy

**Date of Meeting:** 1st September 2015  
**Start time:** 1:00pm  
**End time:** 1:45pm  
**Location:** Erwin’s Office  
**Minutes prepared by:** Adrian Di Nardo  
**Purpose of meeting:** Discuss work completed since last meeting and progress of the system build.

### 1. Agenda
- Review minutes from previous meeting
- Discuss work completed since last meeting
- Discuss the build progress of the plasma device
- See if the roadmap goals and dates are being achieved

### 2. Attendance at meeting
- **Present:** Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa  
- **Apologies:** Cris Birzer  
- **Absent:**

### 3. Review of previous minutes
- Minutes of 25/8/2015 are accepted

### 4. Progress since last meeting
- Device componentry has been collected and connected

### 5. Current Minutes (Notes, Decisions, Issues)
- All work is to STOP until risk assessments (RA) and Safe operating procedures (SOP) are created and signed off
- Risk assessment needs to be very detailed, ie. every single way be could be electrocuted not just that electrocution is a risk
- Discussed the issue that we have been having due to a mosfet, and that it was used by other people before we got it
- Discussed polo tops for mech expo
  - Erwin suggested to talk to Loretta from the front office
- ACTION – complete risk assessments and SOPs immediately
- Don’t do the RAs and SOPs for the sake of doing paper work, actually think about them and the issues with the project
Meeting minutes 1989. Water purification from kinetic energy

6. Action Items

<table>
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<td>1. RAs and SOPs</td>
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8. Next Meeting

Date: 08/09/2015  Time: 1:00pm  Location: Erwin’s office

Agenda:
- Apologies
- Review previous minutes
- Discuss RAs and SOPs
# Meeting minutes

**1989. Water Treatment Using Non-Thermal Plasma**

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<th>Date of Meeting:</th>
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<th>Start time: 1:00pm</th>
<th>End time: 1:45pm</th>
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<td>Location:</td>
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<tr>
<td>Minutes prepared by:</td>
<td>William Leonard</td>
<td></td>
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<tr>
<td>Purpose of meeting:</td>
<td>Discuss work completed since last meeting and update on initial testing</td>
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## 1. Agenda

- Apologies
- Review previous minutes
- Discuss the risk assessment and SOP

## 2. Attendance at meeting

Present: Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa

Apologies: Cris Birzer

Absent:

## 3. Review of previous minutes

Minutes of 01/09/2015 are accepted

## 4. Progress since last meeting

- Risk Assessment has been completed
- A SOP was developed
- Further development of the device has been made
5. Current Minutes (Notes, Decisions, Issues)

- The risk assessment is still a bit general, however thought has been demonstrated and was accepted.
  - The risk assessment needs more evidence of the device itself e.g. pictures. For Erwin to be satisfied that the system is safe.
  - It was decided that the group should bring the device into the university to demonstrate how it will work without actually starting it.
- ACTION – Bring the device into the university to show Erwin at 1.30pm on Wednesday.
- It was decided that the device could remain and be operated in the corrosion lab with no E.coli.
- The SOP was still too general therefore it needs to be updated so that it will be relevant and to make sure that it will be used.
- ACTION – Complete the SOP with more detail.
- Discussed the costs so far for the project and signing them off because a note on the top of the reimbursement form says that receipts have to be submitted within three months of the purchase date otherwise they are voided.
- Discussion about Dr Connor Thomas
  - The reagents have arrived and are waiting in a fridge in one of his labs.
  - He will be at the university on Thursday morning for a meeting to discuss where we go from here in terms of testing.
  - Dr Connor Thomas would like an SOP to help him understand the system a bit more.

6. Action Items

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<td>1. Bring device to Erwin</td>
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<td>2. Fix up the SOP</td>
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8. Next Meeting

Date: (DD/MM/YYYY) 15/09/2015  Time: 1:00pm  Location: Erwin’s office

Agenda:
- Apologies
- Review previous minutes
- Discuss meeting with Dr Connor Thomas
- Discuss the SOP
- Discuss any developments with initial testing
Meeting minutes 1989. Water Treatment Using Non-Thermal Plasma

Date of Meeting: 20th October 2015  
Start time: 1:00pm  
End time: 1:45pm

Location: Erwin's Office  
Minutes prepared by: Ruben de Vries

Purpose of meeting: Discuss testing and remaining deliverables

1. Agenda
   • Progress report of testing
   • Ingenuity
   • Final Report

2. Attendance at meeting

Present: Adrian Di Nardo, Ruben de Vires, Juliano Paradiso, William Leonard, Erwin Gamboa, Cris Birzer

Apologies: 

Absent: 

3. Review of previous minutes

Minutes of 20/10/2015 are accepted

4. Progress since last meeting
   • First lot of E.coli testing complete
   • Further progress on the final report
5. Current Minutes (Notes, Decisions, Issues)

- The first lot of E.coli testing was completed on Monday, 19/10/2015
  - The device was run at 24V and 275Hz which should produce peak ozone
  - It was tested for 1, 2, 3, 4 and 5 mins
    - All tests were fine except the 5min created too much heat in the electronics
  - A 2 log reduction was achieved
  - Dr. Connor Thomas conducted most of the testing procedure
  - A pump was introduced as instructed by Dr. Connor Thomas, this should circulate the water
  - Ozone readings were taken at the same time
- Further E.coli testing will be grown on Wednesday, tested on Thursday and counted on Friday
  - The pump is planned to be introduced again
- Ingenuity: The device will not be running
- Final Report
  - Progress is slightly behind schedule but a complete draft will reviewed by Erwin on Saturday morning and Cris on Monday morning at 9

6. Action Items

<table>
<thead>
<tr>
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<tr>
<td>Prepare for Ingenuity</td>
<td>All Students</td>
<td>26 / 10 / 2015</td>
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<tr>
<td>Complete draft of report</td>
<td>All Students</td>
<td>23 / 10 / 2015</td>
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8. Next Meeting

<table>
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<th>Time:</th>
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<tr>
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<td>N / A</td>
<td>N / A</td>
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</tbody>
</table>
Graves Lab Procedure

Procedure: ___ Colorimetric (indigo) ozone assay
Date: ______ August 27, 2013
Created by: ___ Carly Anderson (CEA)___

Purpose: Determine the concentration of ozone in a solution containing between XXX and XXX mM (XXX-XXX mg/L).

Safety:
- Reagents include strong acids. Handle with care.

Materials:

**Indigo Stock Solution:** (pre-made stock solution lives in the Clark lab cold room on common shelf.)
100 mL distilled water
100 ul 85% phosphoric acid (H₃PO₄)
77 mg potassium indigo trisulfonate

**Indigo Reagent:** (make fresh the day of the assay)
For 10ml:
200 ul indigo stock solution
100 mg sodium phosphate (NaH₂PO₄) [buffer]
70 ul phosphoric acid (H₃PO₄)
+ distilled water to 10 ml

Procedure:

1. Prepare indigo reagent according to the recipe above.

2. Immediately after sample is taken, add indigo reagent (1:1 vol/vol ratio) to sample in a small eppendorf tube and vortex. (The half-life of ozone in solution is very short, so reagent should be added ASAP for an accurate reading. The mixture with reagent should be stable for several hours.)

Note: The indigo reagent is blue. If the sample contains ozone, it will react with the indigo in the reagent and reduce the color. The more clear the sample+reagent mixture is, the more ozone it contains.

3. Measure the absorbance at 600nm of a blank – indigo reagent + untreated sample (or water) – using the UV-vis spectrometer in the Clark lab (light side). The cuvette for the UV-vis in Clark Lab is hidden in MP’s stuff. Use this – you only need to add about 100ul of sample to the cuvette. Make sure the window heading in the program says “cuvette”. Then click “Ref”.

4. Empty and rinse the cuvette with water (~3x) and dry (blow air or use vacuum...)

5. Add 100ul of sample+reagent mixture to the cuvette. Click “Read” to measure absorbance at 600nm.
6. ZM/MP use a correlation coefficient of -2.0389 x the raw absorbance to calculate the O₃ concentration, in mg/L.

References/Supporting Information:

Paper describing method:
J: MOSFET Data Sheet

Features
- Advanced Process Technology
- Ultra Low On-Resistance
- 175°C Operating Temperature
- Fast Switching
- Repetitive Avalanche Allowed up to Tjmax

Description
Specifically designed for Automotive applications, this HEXFET® Power MOSFET utilizes the latest processing techniques to achieve extremely low on-resistance per silicon area. Additional features of this design are a 175°C junction operating temperature, fast switching speed and improved repetitive avalanche rating. These features combine to make this design an extremely efficient and reliable device for use in Automotive applications and a wide variety of other applications.

Absolute Maximum Ratings

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<td>300</td>
<td>mJ</td>
</tr>
<tr>
<td>EAS (tested)</td>
<td>690</td>
<td>mJ</td>
</tr>
<tr>
<td>IAR</td>
<td>See Fig. 12a, 12b, 15, 16</td>
<td>A</td>
</tr>
<tr>
<td>Tj</td>
<td>-55 to +175</td>
<td>°C</td>
</tr>
<tr>
<td>TSTG</td>
<td>300 (1.6mm from case)</td>
<td></td>
</tr>
</tbody>
</table>

Thermal Resistance

<table>
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<tr>
<th>Parameter</th>
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<th>Units</th>
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<tbody>
<tr>
<td>Rjc</td>
<td>0.45</td>
<td>°C/W</td>
<td></td>
</tr>
<tr>
<td>Rcs</td>
<td>0.50</td>
<td>——</td>
<td></td>
</tr>
<tr>
<td>Rja</td>
<td>62</td>
<td>——</td>
<td></td>
</tr>
<tr>
<td>Rja</td>
<td>40</td>
<td>——</td>
<td></td>
</tr>
</tbody>
</table>

HEXFET® is a registered trademark of International Rectifier.
www.irf.com

International Rectifier

AUTOMOTIVE MOSFET

HEXFET® Power MOSFET

VDS = 75V
RDS(on) = 4.5mΩ
ID = 75A

www.irf.com
IRF2907Z/S/L

Static @ T_J = 25°C (unless otherwise specified)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>V(BR)DSS</td>
<td>75</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>VGS = 0V, IP = 250µA</td>
</tr>
<tr>
<td>mV(BR)DSS/AT_J</td>
<td>0.069</td>
<td>—</td>
<td>—</td>
<td>V/°C</td>
<td>Reference to 25°C, IP = 1mA</td>
</tr>
<tr>
<td>R_DS(on)</td>
<td>3.5</td>
<td>—</td>
<td>4.5</td>
<td>mΩ</td>
<td>VGS = 10V, IR = 75A</td>
</tr>
<tr>
<td>V_GS(th)</td>
<td>2.0</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>VGS = VDS, IP = 250µA</td>
</tr>
<tr>
<td>gfs</td>
<td>180</td>
<td>—</td>
<td>—</td>
<td>mA</td>
<td>VGS = 25V, IR = 75A</td>
</tr>
<tr>
<td>IDS</td>
<td>—</td>
<td>—</td>
<td>250</td>
<td>mA</td>
<td>VGS = 70V, VDS = 0V, T_J = 125°C</td>
</tr>
<tr>
<td>UGS</td>
<td>—</td>
<td>—</td>
<td>200</td>
<td>mA</td>
<td>VGS = 20V</td>
</tr>
<tr>
<td>Q_G</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>nC</td>
<td>—</td>
</tr>
<tr>
<td>I_D</td>
<td>—</td>
<td>—</td>
<td>270</td>
<td>mA</td>
<td>—</td>
</tr>
<tr>
<td>Q_P</td>
<td>46</td>
<td>—</td>
<td>—</td>
<td>nC</td>
<td>VGS = 60V</td>
</tr>
<tr>
<td>Q_D</td>
<td>65</td>
<td>—</td>
<td>—</td>
<td>nC</td>
<td>VGS = 10V</td>
</tr>
<tr>
<td>t_on</td>
<td>19</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td>VGS = 38V</td>
</tr>
<tr>
<td>t_off</td>
<td>97</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td>IB = 75A</td>
</tr>
<tr>
<td>L_D</td>
<td>140</td>
<td>—</td>
<td>—</td>
<td>Ω</td>
<td>R_G = 2.5Ω</td>
</tr>
<tr>
<td>L_S</td>
<td>100</td>
<td>—</td>
<td>—</td>
<td>Ω</td>
<td>VGS = 10V</td>
</tr>
<tr>
<td>L</td>
<td>5.0</td>
<td>—</td>
<td>—</td>
<td>mH</td>
<td>Between lead, from package and center of die contact</td>
</tr>
<tr>
<td>Ciss</td>
<td>7500</td>
<td>—</td>
<td>—</td>
<td>pF</td>
<td>VGS = 0V</td>
</tr>
<tr>
<td>Coss</td>
<td>970</td>
<td>—</td>
<td>—</td>
<td>pF</td>
<td>VGS = 25V</td>
</tr>
<tr>
<td>Crss</td>
<td>510</td>
<td>—</td>
<td>—</td>
<td>pF</td>
<td>f = 1.0MHz, See Fig.5</td>
</tr>
<tr>
<td>Ciss eff</td>
<td>3640</td>
<td>—</td>
<td>—</td>
<td>pF</td>
<td>VGS = 0V, VGS = 1.0V, f = 1.0MHz</td>
</tr>
<tr>
<td>Coss eff</td>
<td>650</td>
<td>—</td>
<td>—</td>
<td>pF</td>
<td>VGS = 0V, VGS = 60V, f = 1.0MHz</td>
</tr>
<tr>
<td>Coss eff</td>
<td>1020</td>
<td>—</td>
<td>—</td>
<td>pF</td>
<td>VGS = 0V, VGS = 60V to 60V</td>
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</table>

Diode Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
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<tr>
<td>ISD</td>
<td>—</td>
<td>—</td>
<td>75</td>
<td>A</td>
<td>MOSFET symbol</td>
</tr>
<tr>
<td>ISM</td>
<td>—</td>
<td>—</td>
<td>680</td>
<td>pA</td>
<td>showing the integral reverse p-n junction diode.</td>
</tr>
<tr>
<td>V_FD</td>
<td>—</td>
<td>—</td>
<td>1.3</td>
<td>V</td>
<td>T_J = 25°C, IS = 75A, VGS = 0V</td>
</tr>
<tr>
<td>t_Rp</td>
<td>41</td>
<td>—</td>
<td>61</td>
<td>ns</td>
<td>T_J = 25°C, IP = 75A, VDD = 38V</td>
</tr>
<tr>
<td>Q_r</td>
<td>59</td>
<td>—</td>
<td>89</td>
<td>nC</td>
<td>di/dt = 100A/µs</td>
</tr>
<tr>
<td>t_Rn</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td>intrinsic turn-on time is negligible (turn-on is dominated by LS+LD)</td>
</tr>
</tbody>
</table>

Notes:

1. Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11).
2. Limited by T_max, starting T_J = 25°C, L=0.1mH, R_G = 25Ω, I_D = 75A, V_DS = 10V. (Part not recommended for use above this value).
3. R_D ≤ 75A, di/dt ≤ 340A/µs, V_DS ≤ V_anos, T_J ≤ 175°C.
4. Pulse width ≤ 1.0ms; duty cycle ≤ 2%.
5. C_DSS eff. is a fixed capacitance that gives the same charging time as C_DSS while V_DS is rising from 0 to 80% V_SSS.
6. Limited by T_max, see Fig.12a, 12b, 15, 16 for typical repetitive avalanche performance.
7. This value determined from sample failure population. 100% tested to this value in production.
8. This is applied to D_Pak when mounted on 1” square PCB (FR-4 or G-10 Material). For recommended footprint and soldering techniques refer to application note AN-994.
9. R_D is measured at T_J of approximately 90°C.

www.irf.com
Fig 1. Typical Output Characteristics

Fig 2. Typical Output Characteristics

Fig 3. Typical Transfer Characteristics

Fig 4. Typical Forward Transconductance vs. Drain Current
IRF2907Z/S/L

Fig 5. Typical Capacitance vs. Drain-to-Source Voltage

Fig 6. Typical Gate Charge vs. Gate-to-Source Voltage

Fig 7. Typical Source-Drain Diode Forward Voltage

Fig 8. Maximum Safe Operating Area
Fig 9. Maximum Drain Current vs. Case Temperature

Fig 10. Normalized On-Resistance vs. Temperature

Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

Notes:
1. Duty Factor D = t1/t2
2. Peak Tj = Pdm x Zthjc + Tc

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IRF2907Z/S/L

Fig 12a. Unclamped Inductive Test Circuit

Fig 12b. Unclamped Inductive Waveforms

Fig 12c. Maximum Avalanche Energy vs. Drain Current

Fig 13a. Basic Gate Charge Waveform

Fig 13b. Gate Charge Test Circuit

Fig 14. Threshold Voltage vs. Temperature

www.irf.com
Notes on Repetitive Avalanche Curves, Figures 15, 16:
(For further info, see AN-1005 at www.irf.com)
1. Avalanche failures assumption:
   A purely thermal phenomenon and failure occurs at a
temperature far in excess of $T_{\text{max}}$. This is validated for
every part type.
2. Safe operation in Avalanche is allowed as long as $T_j$ is
   not exceeded.
3. Equation below based on circuit and waveforms shown in
   Figures 12a, 12b.
4. $PD_{\text{ave}} = \text{Average power dissipation per single}
   \text{avalanche pulse.}$
5. $BV = \text{Rated breakdown voltage (1.3 factor accounts for}
   \text{voltage increase during avalanche).}$
6. $I_{av} = \text{Allowable avalanche current.}$
7. $\Delta T = \text{Allowable rise in junction temperature, not to exceed}$
   $T_{\text{max}}$ (assumed as 25°C in Figure 15, 16).
$v_{av} = \text{Average time in avalanche.}$
$D = \text{Duty cycle in avalanche = } I_{av} \cdot f$
$Z_{thJC}(D, I_{av}) = \text{Transient thermal resistance, see figure 11)}$

$$PD_{\text{ave}} = \frac{1}{2} (1.3 \cdot BV \cdot I_{av}) = \frac{\Delta T \cdot Z_{thJC}}{1.3}$$

$$I_{av} = 2 \cdot \frac{1}{T \cdot (1.3 \cdot BV \cdot Z_{th})}$$

$$E_{AS}(AR) = PD_{\text{ave}} / v_{av}$$
IRF2907Z/S/L

Fig 17. Peak Diode Recovery dv/dt Test Circuit for N-Channel HEXFET® Power MOSFETs

Fig 18a. Switching Time Test Circuit

Fig 18b. Switching Time Waveforms
TO-220AB Package Outline
Dimensions are shown in millimeters (inches)

NOTES:
2. CONTROLLING DIMENSION: INCH
3. OUTLINE CONFORMS TO JEDEC OUTLINE TO-220AB.
4. HEATSINK & LEAD MEASUREMENTS DO NOT INCLUDE BURRS.

TO-220AB Part Marking Information

EXAMPLE: THIS IS AN IRF1010 LOT CODE E 1789 ASSEMBLED ON WW 19, 1997 IN THE ASSEMBLY LINE 'C'

Note: "P" in assembly line position indicates "Lead-Free"

www.irf.com
IRF2907Z/S/L

D²Pak Package Outline

Dimensions are shown in millimeters (inches)

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DIMENSIONS</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.06</td>
<td>.160</td>
</tr>
<tr>
<td>A1</td>
<td>.312</td>
<td>.005</td>
</tr>
<tr>
<td>b</td>
<td>.999</td>
<td>.020</td>
</tr>
<tr>
<td>b1</td>
<td>.999</td>
<td>.020</td>
</tr>
<tr>
<td>h2</td>
<td>1.40</td>
<td>.050</td>
</tr>
<tr>
<td>c</td>
<td>.433</td>
<td>.017</td>
</tr>
<tr>
<td>c1</td>
<td>.745</td>
<td>.029</td>
</tr>
<tr>
<td>c2</td>
<td>1.40</td>
<td>.050</td>
</tr>
<tr>
<td>D</td>
<td>8.51</td>
<td>.335</td>
</tr>
<tr>
<td>D1</td>
<td>5.33</td>
<td>.210</td>
</tr>
<tr>
<td>E</td>
<td>9.65</td>
<td>.360</td>
</tr>
<tr>
<td>E1</td>
<td>6.22</td>
<td>.245</td>
</tr>
<tr>
<td>e</td>
<td>2.54</td>
<td>.100</td>
</tr>
<tr>
<td>L</td>
<td>14.01</td>
<td>.575</td>
</tr>
<tr>
<td>L1</td>
<td>1.75</td>
<td>.070</td>
</tr>
<tr>
<td>L2</td>
<td>1.65</td>
<td>.065</td>
</tr>
<tr>
<td>L3</td>
<td>1.27</td>
<td>.050</td>
</tr>
<tr>
<td>L4</td>
<td>0.25</td>
<td>.010</td>
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<tr>
<td>m</td>
<td>17.76</td>
<td>.700</td>
</tr>
<tr>
<td>m1</td>
<td>8.89</td>
<td>.350</td>
</tr>
<tr>
<td>n</td>
<td>11.13</td>
<td>.450</td>
</tr>
<tr>
<td>o</td>
<td>2.08</td>
<td>.082</td>
</tr>
<tr>
<td>p</td>
<td>3.01</td>
<td>.150</td>
</tr>
<tr>
<td>e</td>
<td>90°</td>
<td>90°</td>
</tr>
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</table>

D²Pak Part Marking Information

EXAMPLE: THIS IS AN IRF530S WITH LOT CODE 9624 ASSEMBLED ON WW02, 2000 IN THE ASSEMBLY LINE 'L'

Note: 'P' in assembly line position indicates 'Lead-Free'

www.irf.com
TO-262 Package Outline
Dimensions are shown in millimeters (inches)

TO-262 Part Marking Information

EXAMPLE:  THIS IS AN IRF3203L
LOT CODE 789
ASSEMBLED ON WW 19, 1997
IN THE ASSEMBLY LINE "C"

www.irf.com
IRF2907Z/S/L

D²Pak Tape & Reel Information
Dimensions are shown in millimeters (inches)

NOTES:
1. CONFORMS TO EIA-418.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION MEASURED @ HUB.
4. INCLUDES FLANGE DISTORTION @ OUTER EDGE.

TO-220AB package is not recommended for Surface Mount Application.

Data and specifications subject to change without notice.
This product has been designed and qualified for the Automotive [Q101] market.
Qualification Standards can be found on IR's Web site.

IR WORLD HEADQUARTERS: 233 Kansas St., El Segundo, California 90245, USA Tel: (310) 252-7105
TAC Fax: (310) 252-7903
Visit us at www.irf.com for sales contact information, 06/04

www.irf.com
K: Diode

LOW DROP POWER SCHOTTKY RECTIFIER

MAIN PRODUCTS CHARACTERISTICS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF(AV)</td>
<td>3 A</td>
<td>1N5820</td>
<td>1N5821</td>
</tr>
<tr>
<td>VRRM</td>
<td>40 V</td>
<td>100°C</td>
<td></td>
</tr>
<tr>
<td>TF(max)</td>
<td>0.475 V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FEATURES AND BENEFITS

- VERY SMALL CONDUCTION LOSSES
- NEGLIGIBLE SWITCHING LOSSES
- EXTREMELY FAST SWITCHING
- LOW FORWARD VOLTAGE DROP
- AVALANCHE CAPABILITY SPECIFIED

DESCRIPTION

Axial Power Schottky rectifier suited for Switch Mode Power Supplies and high frequency DC to DC converters. Packaged in DO-201AD these devices are intended for use in low voltage, high frequency inverters, free wheeling, polarity protection and small battery chargers.

ABSOLUTE RATINGS (limiting values)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRRM</td>
<td>Repetitive peak reverse voltage</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>IF(RMS)</td>
<td>RMS forward current</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>IF(AV)</td>
<td>Average forward current</td>
<td>Tj = 100°C  δ = 0.5</td>
<td>3</td>
</tr>
<tr>
<td>IFSM</td>
<td>Surge non repetitive forward current</td>
<td>tp = 10 ms Sinusoidal</td>
<td>80</td>
</tr>
<tr>
<td>PARM</td>
<td>Repetitive peak avalanche power</td>
<td>tp = 1µs  Tj = 25°C</td>
<td>1700</td>
</tr>
<tr>
<td>TSIG</td>
<td>Storage temperature range</td>
<td>-65 to +150°C</td>
<td></td>
</tr>
<tr>
<td>TJ</td>
<td>Maximum operating junction temperature *</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>dV/dt</td>
<td>Critical rate of rise of reverse voltage</td>
<td>10000</td>
<td></td>
</tr>
</tbody>
</table>

*: \[ \frac{dP_{tot}}{dT_{j}} < \frac{1}{R_{th}(j-a)} \] thermal runaway condition for a diode on its own heatsink

July 2003 - Ed: 3A
1N582x

THERMAL RESISTANCES

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<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>$R_{th}(j-a)$</td>
<td>Junction to ambient</td>
<td>Lead length = 10 mm</td>
<td>80</td>
</tr>
<tr>
<td>$R_{th}(j-l)$</td>
<td>Junction to lead</td>
<td>Lead length = 10 mm</td>
<td>25</td>
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STATIC ELECTRICAL CHARACTERISTICS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Tests Conditions</th>
<th>1N5820</th>
<th>1N5821</th>
<th>1N5822</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_R$</td>
<td>Reverse leakage current</td>
<td>$T_j = 25^\circ\text{C}$</td>
<td>$V_R = V_{RRM}$</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>$T_j = 100^\circ\text{C}$</td>
<td></td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>mA</td>
</tr>
<tr>
<td>$V_F$</td>
<td>Forward voltage drop</td>
<td>$T_j = 25^\circ\text{C}$</td>
<td>$I_F = 3\text{ A}$</td>
<td>0.475</td>
<td>0.5</td>
<td>0.525</td>
</tr>
<tr>
<td></td>
<td>$T_j = 25^\circ\text{C}$</td>
<td>$I_F = 9.4\text{ A}$</td>
<td>0.85</td>
<td>0.9</td>
<td>0.95</td>
<td>V</td>
</tr>
</tbody>
</table>

Pulse test: * $t_p = 380\mu\text{s}$, $\delta < 2\%$

To evaluate the conduction losses use the following equations:

\[
P = 0.33 x I_{F(AV)} + 0.035 I_{F(RMS)}^2 \text{ for 1N5820 / 1N5821}
\]
\[
P = 0.33 x I_{F(AV)} + 0.060 I_{F(RMS)}^2 \text{ for 1N5822}
\]

Fig. 1: Average forward power dissipation versus average forward current (1N5820/1N5821).

Fig. 2: Average forward power dissipation versus average forward current (1N5822).

Fig. 3: Normalized avalanche power derating versus pulse duration.

Fig. 4: Normalized avalanche power derating versus junction temperature.
Fig. 5-1: Average forward current versus ambient temperature (δ=0.5) (1N5820/1N5821).

Fig. 5-2: Average forward current versus ambient temperature (δ=0.5) (1N5822).

Fig. 6-1: Non repetitive surge peak forward current versus overload duration (maximum values) (1N5820/1N5821).

Fig. 6-2: Non repetitive surge peak forward current versus overload duration (maximum values) (1N5822).

Fig. 7: Relative variation of thermal impedance junction to ambient versus pulse duration (epoxy printed circuit board, e(Cu)=35mm, recommended pad layout).

Fig. 8: Junction capacitance versus reverse voltage applied (typical values).
APPENDIX K. DIODE

Water Treatment Using Non-Thermal Plasma

Fig. 9-1: Reverse leakage current versus reverse voltage applied (typical values) (1N5820/1N5821).

Fig. 9-2: Reverse leakage current versus reverse voltage applied (typical values) (1N5822).

Fig. 10-1: Forward voltage drop versus forward current (typical values) (1N5820/1N5821).

Fig. 10-2: Forward voltage drop versus forward current (typical values) (1N5822).

Fig. 11: Non repetitive surge peak forward current versus number of cycles.
APPENDIX K. DIODE Water Treatment Using Non-Thermal Plasma

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1N582x

PACKAGE MECHANICAL DATA
DO-201AD plastic

<table>
<thead>
<tr>
<th>REF.</th>
<th>DIMENSIONS</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Millimeters</td>
<td>Inches</td>
</tr>
<tr>
<td>Min.</td>
<td>Max.</td>
<td>Min.</td>
</tr>
<tr>
<td>A</td>
<td>9.50</td>
<td>0.374</td>
</tr>
<tr>
<td>B</td>
<td>25.40</td>
<td>1.000</td>
</tr>
<tr>
<td>▲ C</td>
<td>5.30</td>
<td>0.209</td>
</tr>
<tr>
<td>▲ D</td>
<td>1.30</td>
<td>0.051</td>
</tr>
<tr>
<td>E</td>
<td>1.25</td>
<td>0.049</td>
</tr>
</tbody>
</table>

B 25.40 1.000
♠ C 5.30 0.209
♠ D 1.30 0.051
E 1.25 0.049

1N582x Part number cathode ring DO-201AD 1.12g 600 Ammopack
1N582xRL Part number cathode ring DO-201AD 1.12g 1900 Tape & reel

EPOXY MEETS UL94, V0

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## L: WHO Table

### Table 7.1 Pathogens transmitted through drinking-water

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Health significance(^a)</th>
<th>Persistence in water supplies(^b)</th>
<th>Resistance to chlorine(^d)</th>
<th>Relative infectivity(^e)</th>
<th>Important animal source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burkholderia pseudomallei</td>
<td>High</td>
<td>May multiply</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Campylobacter jejuni, C. coli</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Escherichia coli – Pathogenic(^1)</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>E. coli – Enterohaemorrhagic</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Francisella tularensis</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Legionella spp.</td>
<td>High</td>
<td>May multiply</td>
<td>Low</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Leptospira</td>
<td>High</td>
<td>Long</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Mycobacteria (non-tuberculous)</td>
<td>Low</td>
<td>May multiply</td>
<td>High</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Salmonella Typhi</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Other salmonellae</td>
<td>High</td>
<td>May multiply</td>
<td>Low</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>High</td>
<td>Short</td>
<td>Low</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Vibrio cholerae</td>
<td>High</td>
<td>Short to long(^2)</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adenoviruses</td>
<td>Moderate</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Astroviruses</td>
<td>Moderate</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Enteroviruses</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Hepatitis A virus</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Hepatitis E virus</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>Potentially</td>
</tr>
<tr>
<td>Noroviruses</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>Potentially</td>
</tr>
<tr>
<td>Rotaviruses</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Sapoviruses</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>High</td>
<td>Potentially</td>
</tr>
<tr>
<td><strong>Protozoa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acanthamoeba spp.</td>
<td>High</td>
<td>May multiply</td>
<td>High</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Cryptosporidium hominis/parvum</td>
<td>High</td>
<td>Long</td>
<td>High</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Cyclospora cayetanensis</td>
<td>High</td>
<td>Long</td>
<td>High</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Entamoeba histolytica</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Giardia intestinalis</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Naegleria fowleri</td>
<td>High</td>
<td>May multiply(^7)</td>
<td>Low</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td><strong>Helminths</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dracunculus medinensis</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Schistosoma spp.</td>
<td>High</td>
<td>Short</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
</tbody>
</table>

\(^a\) This table contains pathogens for which there is some evidence of health significance related to their occurrence in drinking-water supplies. More information on these and other pathogens is presented in chapter 11.

\(^b\) Health significance relates to the incidence and severity of disease, including association with outbreaks.

\(^c\) Detection period for infective stage in water at 20 °C: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month.

\(^d\) When the infective stage is freely suspended in water treated at conventional doses and contact times and pH between 7 and 8. Low means 99% inactivation at 20 °C generally in < 1 min, moderate 1–30 min and high > 30 min. It should be noted that organisms that survive and grow in biofilms, such as Legionella and mycobacteria, will be protected from chlorination.

\(^e\) From experiments with human volunteers, from epidemiological evidence and from experimental animal studies. High means infective doses can be 1–10\(^5\) organisms or particles, moderate 10\(^5\)–10\(^6\) and low > 10\(^6\).

\(^1\) Includes enteropathogenic, enterotoxigenic, enteroinvasive, diffusely adherent and enteroaggregative.

\(^5\) Vibrio cholerae may persist for long periods in association with copepods and other aquatic organisms.

\(^7\) In warm water.

Figure 15. Pathogens transmitted through drinking water (WHO 2011)