A Review of Water Disinfection Technology to Determine Suitable Equipment for Use at Sea for the Disinfection of Seawater

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The Sea Fish Industry Authority
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Summary

Supplies of clean water are essential for the industry to maintain high standards of hygiene and quality. For some uses of seawater, regulations demand that the water is free from microbiological contamination that may adversely effect the safety of fish products. In an operation such as shrimp processing where the cooked product is cooled in seawater, contamination as a result of using unclean seawater may result in food poisoning. Therefore seawater disinfection is necessary.

It is thought that seawater containing a disinfectant residual may also be used to slow the microbiological spoilage of the product itself. For example, using treated water in an RSW system may improve fish quality and extend shelf life.

A review of water disinfection technology was carried out to identify equipment suitable for use at sea for seawater disinfection. Seven types of treatment technology were reviewed. The review considered the equipment required, the safety and the estimated costs associated with each treatment.

Ionization, chlorination, UV and ozone are identified as being potentially suitable and warranting further investigation. Seafish is carrying out practical trials of the selected treatment technologies and these are to be reported separately.

Contents

1. Introduction

Supplies of clean water are essential for the industry to maintain hygiene standards for many fish handling and processing operations.

At sea, and occasionally onshore, seawater is used where a supply of fresh water is unavailable. The Food Safety (Fishery Products on Fishing Vessels) Regulations 1992 demand that the seawater used for this purpose is clean and free from microbial contamination.

The microbiological quality of the seawater is especially important if it comes into contact with a cooked product. Within the brown shrimp industry, seawater is usually used in the cooling and sorting of cooked shrimp. As the quality of seawater cannot be guaranteed there is a risk of contaminating the product, resulting in accelerated spoilage and more importantly the risk of food poisoning. Therefore seawater disinfection is necessary.

It is thought that seawater containing a disinfectant residual may also be used to slow the microbiological spoilage of the product itself. For example, the use of treated water in a refrigerated seawater (RSW) storage system may improve fish quality and extend shelf life.

This report describes a review of water disinfection technology which was carried out with the aim of identifying equipment which would be suitable for the disinfection of seawater on a vessel. Practical trials could then be carried out to determine the performance of selected equipment.

2. Methodology

Seven different types of water disinfection equipment were researched during May 1994. This was achieved by collecting information from industry experts, equipment manufacturers, water consultants, reference texts and literature searches.

The review considered how each disinfectant works, the equipment required, the safety of both the operator and final product as well as the capital and running costs. Technology which looked suitable is discussed in detail in Sections 3 to 6. Technology which was identified as not being suitable is discussed briefly in Section 7.

3. Ozone

3.1 The Basics

Ozone (O_3) is a highly reactive gas consisting of an unstable arrangement of three oxygen atoms. As the ozone reacts with organic material, the arrangement spontaneously breaks down and the ozone becomes a very powerful oxidizing agent.

Ozone kills microorganisms by oxidising and destroying their cell wall. It has the advantage of being able to kill resistant microorganisms such as bacterial spores, cysts and viruses at relatively low concentrations without requiring a long time to work (contact time).

The direct measurement of ozone in fresh water is difficult and expensive. Measurement in seawater is further complicated due to the interference caused by the high concentration of salts present. More commonly, the oxidation-reduction potential (ORP), which is a measure of the oxidative or reducing power of the water is measured and can be related to the amount of ozone in the water. By raising the ORP to 700 millvolts (mV) the water will contain an ozone residual of approximately 0.2 mg/l and sterility should be achieved. The presence of organic contaminants would increase the amount of ozone required to reach this point.

The main use of ozone is in large scale drinking water treatment plants. Ozone is used in areas where the water has a history of contamination with chlorine resistant pathogens such as Giardia cysts or in industrial areas where the water contains organic chemical pollutants, which ozone will oxidise into harmless base constituents. Other applications of ozone include use in swimming pools and aquaria.

Within the fish industry ozone has been used successfully in mollusc depuration systems. Ozone is also used to disinfect seawater for washing purposes and to produce sterile ice. Since 1936 several scientific studies have shown that fish kept in sterile ozonated ice retained their freshness longer than fish in ice made with microbiologically contaminated seawater (Refs: 1 and 2).

3.2 Equipment

A generalisation of the equipment required for the ozonation of water is shown in Figure 1 overleaf.

Because of its inherent instability, ozone is generated at the point of use. It can be produced by either a high voltage discharge or by the photochemical action of UV light.

Most ozone generators use the high voltage discharge method for producing ozone. Dry atmospheric air or oxygen is passed between two discharge plates, across which a high enough energy to split some 0_2 molecules. The free radicals produced combine with other 0_2 molecules to form ozone (0_3).

Generating ozone from moist air produces a powerful acid which quickly corrodes the internal components of the ozone generator, resulting in frequent maintenance.

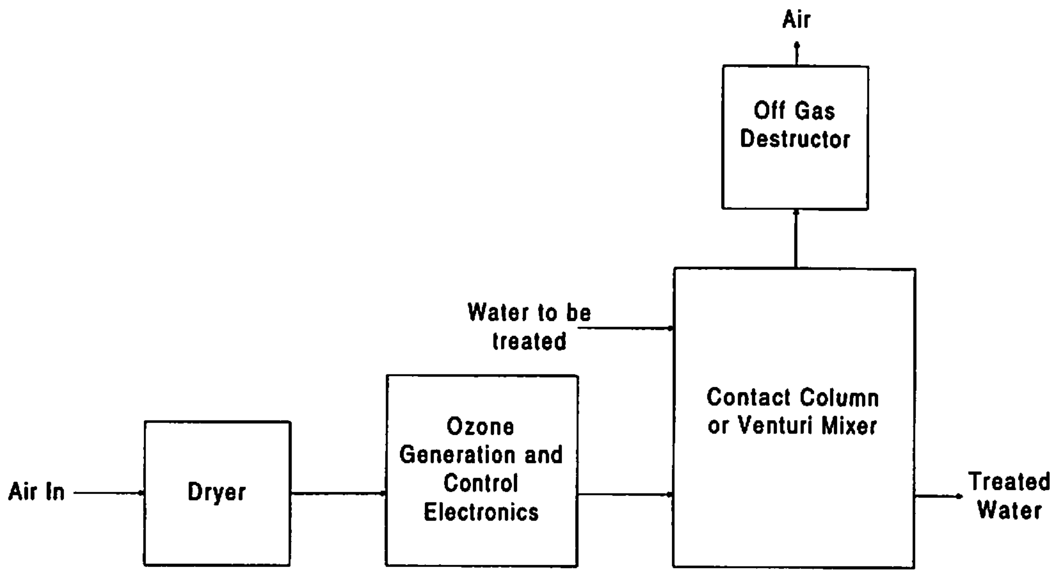

Figure 1 - The equipment required for the ozonation of water

The ozone is then mixed with the water to be treated, using either a Contact Column and/or a Venturi Mixer. A well designed Contact Column consists of a cylinder with an inert packing material to give a high surface area. The efficiency of such a design can reach 95%. Alternatively a Venturi Mixer injects a fine mist of ozone bubbles of a precise size which are readily soluble. Although more compact, this type of equipment can only achieve a mixing efficiency of approximately 70%.

Air which contains ozone which does not pass into solution is passed through an ozone destructor unit which usually consists of UV tubes or activated carbon. Due to the aggressive oxidising nature of ozone, all pipework coming into contact with ozone in either air or water should be made from corrosion resistant materials such as stainless steel or PTFE. PVC pipework can be used but will have a limited life.

The equipment is relatively robust with the exception of the ozone generator and associated control electronics. The air dryers, ozone generator and associated pumps usually require a substantial 240 V AC power supply. Ozone generators and associated equipment are available in a full range of sizes to suit any requirements.

3.3 Safety

A correctly designed ozone water treatment system is essential. Ozone is a highly toxic gas which causes damage to the human respiratory system at very low levels. The occupational exposure standard (OES) is currently set at 0.2 mg/l for 15 minutes. Defective equipment or poor design could cause a build-up of ozone in working areas. Ozone is not only toxic but being a powerful oxidising agent a build-up may result in a fire hazard. An ozone monitoring system/alarm must be installed to protect workers.

Like other chemical disinfectants, ozone produces very small amounts of toxic chemical compounds as it reacts with components of water and seawater. In seawater, ozone oxidises bromide ions to form bromates (BrO_3) and bromoforms (CH Br). Drinking water regulations specify maximum permissible limits for trihalomethanes (THMs) in drinking water, which include some bromine compounds. In applications such as product washing or refrigerated sea water (RSW) treatment, it is likely that only trace amounts of these chemicals would be produced and even smaller amounts transferred to the product.

3.4 Cost

Initial capital equipment cost would be relatively high. Basic ozone water treatment systems with some form of monitoring system would be likely to cost upwards of £5,000 depending on size and sophistication required. Running costs of the equipment should be relatively low.

3.5 Conclusions

It is thought that ozone equipment would not be suitable for use on board small boats due to the limitations of power supply. However, it is thought that ozone may be a viable option for larger boats.

4. Sodium Hypochlorite

4.1 The Basics

Sodium hypochlorite (NaOCl) is a chlorine based disinfectant which is widely available in liquid form up to 15% w/w available chlorine. When sodium hypochlorite is added to water it disassociates to form hypochlorous acid which is the main germicidal agent. Microorganisms are killed as the chemical enters the cell and interferes with the function of vital enzymes.

Sodium hypochlorite will kill most microorganisms given a sufficient dose and contact time. Typically for fresh water with a pH of 8.5 at 10° C and a contact time of one minute, 0.5 mg/l of free available chlorine (FAC) is required to kill 99.6% to 100% of coliform bacteria. In comparison approximately 20 mg/l of FAC is required to give a similar virus kill (Ref. 3). The affectivity of sodium hypochlorite is reduced at lower temperatures, alkaline pH and by the presence of organic contaminants in the water.

The main use of sodium hypochlorite is in small to medium sized drinking water treatment plants. It is also used within the food industry at concentrations of up to 300 mg/l as a final product wash for salad, raw chickens and fish fillets and for general disinfection and hygiene purposes. Other applications of sodium hypochlorite include swimming pool disinfection.

4.2 Equipment

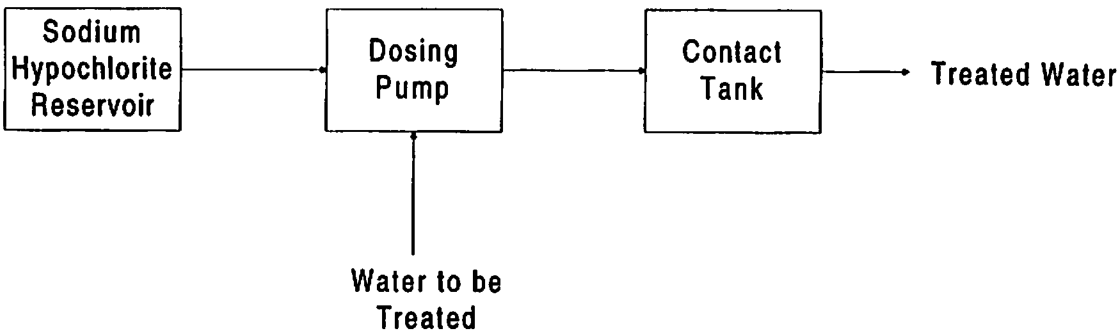

Figure 2 - The equipment required for the sodium hypochlorite dosing of water

Sodium hypochlorite is drawn from the reservoir and dosed into the water to be treated. If the water flow is constant, a simple non proportional dosing pump can be used to deliver the required amount of sodium hypochlorite. Self-adjusting dosing pumps are also available.

A contact tank may be required to ensure thorough mixing and give the required kill for water containing robust microorganisms.

The equipment is simple, reasonably compact and robust. It can be supplied to operate from either 12 V DC, 24 V DC or 240 V AC.

4.3 Safety

Sodium hypochlorite is a relatively safe and stable chemical at the lower concentrations commonly used commercially. However, it is corrosive and can cause irritation to the skin and eyes as a result of careless handling.

Sodium hypochlorite will react with humic and formic acid compounds in water to form trihalomethanes (THMS), bromoforms and chloroforms compounds which are considered to be harmful if consumed in large quantities. Current UK legislation demands that drinking water does not contain more than 0.1 mg/l of trihalomethanes. It is likely that for an operation such as product washing or RSW treatment, only trace amounts of THMS would be transferred to the product. Hypochlorite odour and flavour tainting can occur at high treatment levels.

4.4 Cost

Capital equipment cost would be relatively low. A system to dose a flow of water would cost upwards of £600. However if the requirements for treated water were low, a suitable reservoir tank could be dosed manually and costs would be significantly reduced.

Running costs are also anticipated to be relatively low It would cost approximately 4p to treat $1 m^3$ of water with a chlorine dose of 20 mg/l using sodium hypochlorite bought in bulk.

4.5 Conclusions

It is thought that a sodium hypochlorite dosing system would be suitable for use on board both large and small vessels due to its ruggedness, compact size and low power consumption.

5. Ionization

5.1 The Basics

Copper and silver ions have been used since Roman times to purify drinking water. The Romans realised that by keeping a copper or silver coin in the bottom of a water jug or fountain, the water kept fresh for longer. Copper and silver can now be electrolytically deposited into water giving greater control over the dose received.

Copper and silver ions kill microorganisms by entering the cell and binding to sites which inhibit vital cellular enzymes and reproductive mechanisms (Ref 4).

The biocidal action of copper and silver ions on bacteria, viruses and algae in fresh water is reasonably well documented and the effect of the two ions is thought to be synergenistic. However, to date, no papers were found concerning the biocidal performance of these ions in seawater. The most effective ratio of copper and silver and a suitable dose has not yet been determined. As with other disinfectants, it is thought that the presence of organic material in the water to be treated will increase the dose required.

Ionization is currently being used (mainly in the USA) to control bacterial and algae in spa pools and swimming pools and in cooling towers and hot water systems to control Legionella.

5.2 Equipment

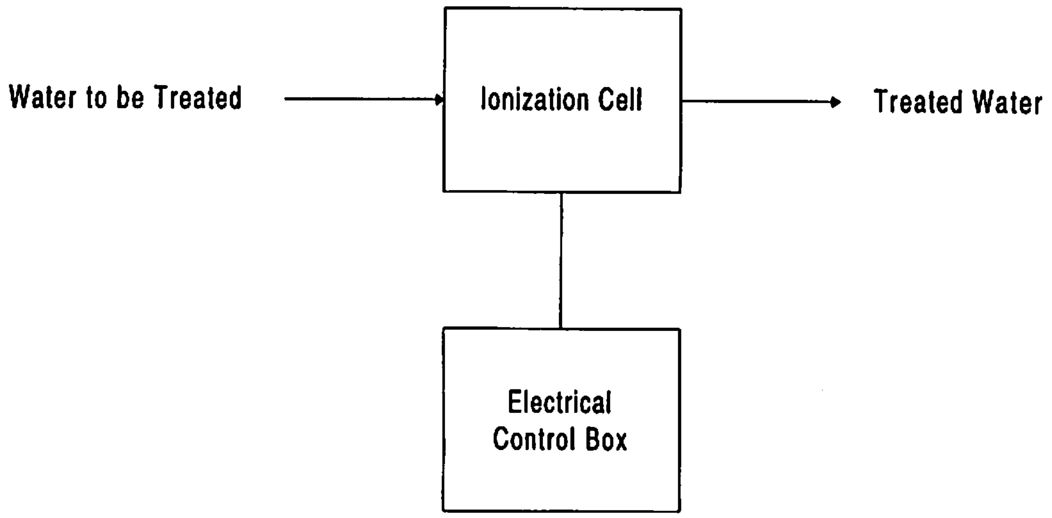

Figure 3 - The equipment required for the electrolytic ionization of water

The water to be treated is passed through the ionization cell which contains electrodes made of a copper and silver alloy. The ratio of copper and silver can be altered to suit a given application. For fresh water treatment the ratio of copper to silver is usually 7:3.

The control box applies a current across the electrodes and metal ions from the anode are deposited into the water and washed away. By varying the current and the water flow rate, the amount of metal ions released into the water can be controlled.

The equipment is extremely compact and robust and can be supplied to operate from either 12 V DC, 24 V DC or 240 V DC.

5.3 Safety

The equipment should not present any risk to the operator. However, copper and silver are harmful if consumed in large amounts. Current UK legislation demands that drinking water contains less than 3 mg/l of copper and 0.08 mg/l of silver if used as a disinfective treatment.

It is likely that for an operation such as product washing or RSW treatment, only trace amounts of metal ions would be transferred to the product.

5.4 Cost

The capital cost of the equipment would be relatively low. A system would be likely to cost upwards of £1,000. The electrodes would have to be replaced as they wear away. Running costs cannot be estimated until the dose required to effectively treat seawater is determined.

5.5 Conclusions

Ionization may be an ideal solution for the disinfection of seawater on large and small boats due to its safety, simplicity and compact size. However, its disinfective performance and running costs must be determined by practical trials.

6. Ultraviolet Light (UV)

6.1 The Basics

Germicidal UV light is short wavelength, high energy ultraviolet light which falls within a very narrow wave band. The optimum germicidal wavelength is 254 nm and germicidal UV lamps are specially designed to produce the maximum amount of light at this wavelength.

The energy carried by the UV light, kills microorganisms by breaking chemical bonds within the deoxyribonucleic acid (DNA) structure, which prevents the cells from replicating.

UV light is effective against most vegetative bacteria, viruses and algae but is less effective against bacterial spores and cysts which can be highly radiation resistant. The dose of UV which is received by the microorganism is reduced by shielding, which occurs if the water is turbid (suspended material), and by absorption, if the water contains a high proportion of dissolved organic matter. A higher UV dose is required to give the same bacterial kill in seawater than fresh water because of the dissolved salts present. The minimum UV dose required to disinfect clean fresh water to drinking water standards is $25mJ/cm^2$.

UV is commonly used in large scale drinking water treatment plants. It has found many applications within the food industry due to its ability to disinfect liquids and surfaces without odour/flavour tainting or the addition of chemicals. Within the fish industry UV is commonly used to treat seawater in mollusc purification systems.

6.2 Equipment

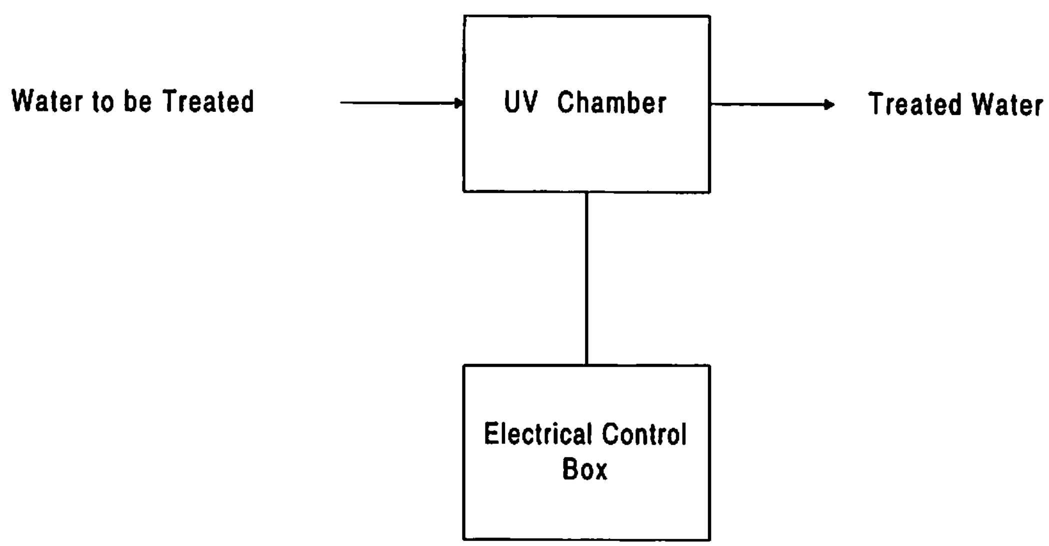

Figure 4 - Equipment required for the UV disinfection of water

The water is passed through a UV chamber which can hold either single or multiple UV tubes each protected inside an individual quartz tube. The water flows around the quartz tube which allows UV light generated by the lamp to pass and kill microorganisms in the water.

Low intensity UV systems usually consists of multiples of 30W or 60W UV tubes. Where more power is required, medium pressure UV lamps are used which give up to 3000W each. The control box contains the electronics required to start and run the UV tubes.

UV equipment is reasonably compact and fairly robust. Higher power systems require a 240 V AC power supply.

6.3 Safety

UV is a relatively safe method for the disinfection of water. Directly viewing the light is harmful but the units are enclosed.

No chemicals are involved and there are no known taints or harmful by-products generated by the process. However, UV light will directly affect plastics and high power lamps can cause deterioration of low quality plastic UV chambers, resulting in harmful plasticisers being deposited into the water. Consequently most high power UV cells are made from stainless steel.

6.4 Costs

The capital cost of UV equipment can be relatively low. A UV system would cost upwards of several hundred pounds depending on power and sophistication. The power of UV required is dictated by the UV absorption coefficient of the water. Determination of the UV absorption coefficient allows the theoretical size of UV equipment and hence the cost to be calculated. The UV absorption coefficient of RSW and of turbid seawater in some areas where shrimp are fished can be very high, which would necessitate expensive, high powered equipment. Filtration may be a possible option to reduce the cost of the UV system required. However, it is anticipated that turbid seawater would quickly block simple cartridge and sand filters, resulting in the need for a complex and expensive self-cleaning filtration system.

6.5 Conclusion

UV is a good method for the disinfection of clean seawater. However, if the UV absorption coefficient of the water is high, small boats would be unable to produce sufficient 240V AC power to run high powered equipment and the cost of that equipment would be prohibitive. Practical trials are required to determine the UV absorbence coefficient of turbid seawater and RSW.

7. Disinfection Treatments Considered Unsuitable

7. 1 Electro Chlorination

An electro chlorination cell can be used to produce sodium hypochlorite solutions from either brine or seawater.

This technology is not considered to be suitable for this application as the equipment is complex, expensive and has a relatively high power requirement. Explosive hydrogen is produced as a by-product which must be ducted away safely.

7.2 Chlorine Dioxide

Chlorine dioxide ($Cl0_2$) is a powerful chemical disinfectant which can be either generated on site using precision mixing and dosing equipment or used in an activatable or pre-activated form.

This technology is not considered to be suitable for this application due to the requirement to store the corrosive chemicals necessary to generate chlorine dioxide and the complexity and capital costs of the generator. Activation of $Cl0_2$ solution requires careful dilution to avoid the liberation of harmful $C1O_2$ gas. A fishing boat would not provide ideal conditions for this to be carried out. A build-up of $C10_2$ in air is not only toxic but auto explosive at concentrations over 14%. Pre-activated, stabilised $C10_2$ solutions are relatively low strength which would require a large quantity to be stored on board. Estimated costs of pre-activated $C10_2$ would be approximately 5 to 20 times more expensive than sodium hypochlorite treatment.

7.3 Hydrogen Peroxide and Peracetic Acid

Hydrogen peroxide and peracetic acid are powerful disinfectants which are used in the food and brewing industry for applications where a non tainting disinfectant is required.

These disinfectants are not considered to be suitable for this application due to handling, cost and safety considerations.

8. Conclusions and Discussions

Of the four disinfection technologies identified as being potentially suitable for the disinfection of seawater on a vessel, ionisation and sodium hypochlorite were considered to be the most suitable for use onboard small boats, due to their simplicity, cost effectiveness, compact dimensions, ruggedness and low power consumption. However, the effectiveness of ionisation for seawater remained to be proven.

For larger boats ozone or UV treatment may be practical although the effectiveness of UV will be reduced by water turbidity.

As a result of this survey, trials are being undertaken to determine the performance and practicality of these four disinfection technologies, both for the cleaning of process water (particularly for inshore shrimp vessels) and for the treatment of RSW/CSW water. Some of this further work is reported in Seafish Reoorts Numbers SR473 and SR466 (Ref's 5 and 6).

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