electrichlor
HYPOCHLORITE GENERATORS

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BALLAST WATER TREATMENT

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1. Background

The transport of pathogens, bacteria, algae and crustaceans in ships' ballast water has become a worldwide problem. The protection of harbors and coastal areas from the invasion by foreign marine species is an issue being addressed by local agencies. While there is not a universal mandatory policy for dumping ballast water, the exchange of ballast water in mid ocean is being adopted by ship owners, as an interim measure until a safer and more effective method is mandated.

The Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO), at its thirty-first session (1-5 July 1991), adopted voluntary International guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges (resolution MEPC. 50(31). This activity was initiated by a number of Countries in the light of problems encountered concerning marine organisms introduced into their waters from ballast water and associated sediments. In 1993 the IMO Assembly adopted these Guidelines by resolution A.774(18), in response to requests from the United Nations Conference on Environment and Development (UNCED). This resolution further addressed the MEPC and Maritime Safety Committee (MSC), requesting them to keep the ballast water issue and the application of the guidelines under review with a view to developing the Guidelines as a basis for a new Annex to MARPOL 73/78.

The IMO Assembly in 1997, by resolution A.868(20), adopted the Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens. The resolutions further requests Governments to take urgent action in applying these new Guidelines, including their dissemination to the shipping industry, and use them as a basis for measures to minimize the risk from the transport of ships' ballast water.

The legally binding measures for the transport of ships' ballast water were to have been adopted in the year 2000, this date has since been amended several times and a draft protocol for the management of ships' ballast water and sediments is being developed for consideration by a diplomatic conference scheduled for 2003.

2. Methodology

The production of sodium hypochlorite from seawater for the control of algae and crustaceans in the cooling water systems of power stations and chemical plants is well known. Onsite generation of hypochlorite has been in use with good effect since the nineteen twenties and has proven to be the most effective method for controlling the growth of marine species in pipework, heat exchangers and condensers of cooling water systems.

This paper is intended to bring a methodology that is simple, safe, easy to manage, cost effective and will provide a 100% kill to all of the water borne nuisance species and pathogens including residents in ballast water and ballast water sediments.

Sanitization and disinfection can be achieved by dosing with sodium hypochlorite (bleach) produced directly from seawater in a sodium hypochlorite generator. The sodium hypochlorite can be produced on-board and either added to the ballast water during pumping, preloading before pumping or post loading after ballast water loading is complete. In all cases de-chlorination before dumping should be carried out to ensure that only sanitized seawater is dumped in rivers and coastal areas.

Chlorination/de-chlorination is being and has been carried out on a large scale throughout the United States and the world in the treatment of wastewater with the sanitized run-off piped into rivers and streams thereby protecting the local marine inhabitants. It is a tried and proven method to fully protect resident species from the effects of chlorinated water.

On-site hypochlorination systems have been around since about 1920 in coastal power generation plants to mitigate and eradicate marine species from fouling the seawater intakes and condensers of cooling water systems. Good quality seawater will provide an equivalent chlorine level between 1500 and 2000mg/l., which is 1/5 below the minimum level of 10,000 mg/l, set by the EPA as a hazardous material.

All untreated water exhibits some chlorine demand. Chlorine demand is the amount of chlorine required to completely kill all bacteria, pathogens, algae and marine growth without any excess chlorine (free chlorine) remaining. Chlorine demand in seawater can vary from 0.2mg/liter in mid ocean waters, to 8-10mg/liter in heavily de-oxygenated and polluted waters in harbors or estuarine environments.

3. Ballast Water Treatment

Three methods are available for the treatment of ballast water with hypochlorite, these are:
(a) Treatment on board – At Source
(b) Treatment on shore – At Source
(c) Treatment on shore – At Destination

Treating ballast water requires the addition of sodium hypochlorite to the ballast water through a hypochlorite generator to provide a free chlorine level above the chlorine demand. Generally a free chlorine level of 1mg/liter is sufficient to ensure that the ballast water is completely sanitized. Seawater is pumped through a hypochlorite generator to provide enough hypochlorite so that when it is mixed with the ballast water, it will provide a free chlorine level of 1-2mg/liter over the ballast water chlorine demand. This can be achieved either from an onboard hypochlorite generator or from a land-based unit. In both cases a reasonably clean seawater source is necessary.

(a) Treating the ballast water onboard "At Source" requires an onboard hypochlorite generator connected to an existing seawater service. The outgoing hypochlorite is then piped to the ballast tanks and allowed to freely mix with the ballast water.
(b) Providing hypochlorite from a shore based "At Source" hypochlorite generator is also possible. A land-based system would require a reasonably clean seawater source and the necessary delivery pipework and connection points for ships to receive hypochlorite prior to taking on ballast water. Each ship would require the necessary internal pipework and an external connection point to enable them to receive shore-based hypochlorite. The size of the hypochlorite generators would be considerably larger than on a ship's installation to allow for multiple ships to be serviced. This method is possibly the easiest to manage as the relevant authority can closely monitor the ballast water treatment.
(c) Treating ballast water onshore "At Destination" requires the installation of pumping equipment and treatment tanks sized to treat the largest expected amount of untreated ballast water. Each ship would require ballast water pumping equipment and an external point for connection to the onshore facility. As the pumping equipment and suction point have to be at the bottom of the ballast tanks, it may not be possible to provide a suitable retrofit without a major refit. However, an adequate ballast water handling system can be accommodated in new vessels. "At Destination" hypochlorite generator or generators provide hypochlorite for adding to the ballast water in the treatment tanks. Fully covered tanks are necessary to eliminate the degeneration of the chlorine in the treated water. The chlorine level in open tanks can deteriorate by 1mg/liter/hour in strong sunlight; this would defeat the sanitizing effect. A separate clean source of seawater for the generation of hypochlorite is necessary as the ballast water to be treated could be contaminated with fuel oil or other products. On shore "At Destination" hypochlorination does not address the issue of ballast water tank sediment treatment, this would have to be addressed elsewhere.

Of the three options, the "At Source" methods are preferred due to:

- Proven technology for the complete elimination of all water borne bacteria, algae, pathogens and crustaceans in ships' ballast water being carried from place to place.
- A technically correct dechlor procedure to ensure that ballast water with chlorine residuals are not released.

However, the On Board "At Source" method is favored as:

- A minimal amount of equipment and pipework are necessary.
- Smaller hypochlorite generators can be used
- Lower capital cost.

There can be a large amount of mud and sediment in the seawater In harbors and coastal areas. When this water is used for ballast water, the sediment can settle out and lock in water borne marine species and pathogens. Hypochlorite dosing addresses this problem, as it will quickly transport the free chlorine through the mud and sediment to attack and destroy all resident marine organisms. This methodology has been proven over many years in aeration and settling ponds in water treatment plants. The equalization of chlorine levels in large water bodies ensures the eradication of marine species locked up in sediment and precipitates. Preloading the ballast tanks with sodium hypochlorite before ballast water filling can further ensure sanitization of sediments. The movement of the ballast water during passage will further enhance sediment treatment.

4. De-chlorination

Unlike industrial plants where low levels of chlorination are used for the control of aquatic species and marine growth in the pipework, heat exchangers and condensers of cooling water systems, ballast water treatment may require higher levels of chlorine. This could cause some destruction of the native marine ecology when dumping ballast water in harbors or coastal areas. *(However, in a lot of cases chlorinated ballast water dumping could help the ecological clean up of polluted harbor waters).*
De-chlorination to a 0-chlorine residual must be carried out before chlorinated water is dumped so it will not destroy the existing marine ecological systems. There are several proven methods to dechlorinate the ballast water before dumping.
The materials used are:
(a) Sulfur dioxide
(b) Activated carbon
(b) Sodium bisulfite
(d) Sodium metabisulfite

(a) Sulfur dioxide gas is widely used in the wastewater industry to dechlorinate treated water in outdoor facilities. It is not recommended for use in confined spaces due to the effect on the human respiratory system. It is therefore not recommended for use in ballast water dechlorination.
(b) Activated carbon is also a method used generally in municipal potable water supply systems, however the large amounts of water to be dechlorinated together with the cost of material and the labor required reconstituting the activated carbon renders, this method unsuitable for marine applications.
(b) Sodium bisulfite ($NaHSO_3$) is a white powder or granular material that can be mixed with seawater. The amount of sodium bisulfite required is 1.46 parts of sodium bisulfite for each 1 part of residual chlorine to be removed. It should be noted that sodium bisulphate is not easily soluble in water and thorough premixing is necessary.
(c) Sodium metabisulfite ($Na_2S_2O_5$) on the other hand is a readily soluble cream-colored powder that is easily mixed with seawater. The amount of sodium metabisulfite required is 1.34 parts of sodium metabisulfite for each 1 part of residual chlorine to be removed.

Both sodium bisulfite and sodium metabisulfite are freely available and the costs are near equal. However, sodium metabisulfite is preferred due to its better mixing properties. For “At Source” hypochlorite installations both onshore and onboard, a small mixing tank would be installed with the necessary pipework and pumping equipment to transport the “Dechlor” to the ballast tanks.
For “At Destination” installations, a larger mixing system would be necessary for the addition of “Dechlor” into the treatment tanks before returning the dechlorinated water to the ocean.

5. Hypochlorination Equipment Size and Operating Costs

To properly describe the equipment necessary for the hypochlorination of ships’ ballast water, the following hypothetical model has been used:

> *A ship with several ballast water or fuel/ballast tanks ranging up to 10,000 metric tonnes. The tanks can be fully or partly filled with seawater ballast to ensure the proper operation and safety of the vessel.*

Ballast tanks are usually filled from a seawater manifold either on deck or just below. Each ballast tank has a either a manual or automatic filling valve connected to the manifold.
When fitted to an existing vessel there are no modifications required to the existing ballast tanks or the filling system, except for the addition of a hypochlorite inlet pipe at a suitable point on the

ballast water manifold. The seawater used for conversion to hypochlorite is taken from a convenient point on the ship's seawater cooling water system; this will allow pre, during or post chlorination to be carried out.
Partly filled tanks can be chlorinated as well as full tanks by generating only the amount of hypochlorite necessary. However, the equipment must be sized for the largest fully filled ballast tank. Due to the limited usage of the hypochlorite generator, it may not be necessary to provide a fully functional spare hypochlorite generator.

Hypochlorite generator sizing for the treatment of 10,000 metric tonnes of seawater to a level of 8mg/liter of equivalent chlorine in a 6 hour period and provide 1mg/l of free chlorine.
10,000mt = 10^7kg. Requires 10kg x 8(mg/l) = 80kg of equivalent chlorine generated over a 6 hour period. This would require a hypochlorite generator capable of producing 13kgs of equivalent chlorine per hour.
The Electrichlor Model EL1-3B would fit the above requirements. The Model EL1-3B is described as follows:

Flow rate through the generator. ………………………………	9 m^3/hr
Number of cell modules. ………………………………………	1
kg/hr of equivalent chlorine ……………………………………..	12 (nom) 15 (max)
Power consumption ……………………………………………	54kW (70kVA)
Power cost assuming 25cents/kWhr. for 80kg of Equivalent chlorine. ……………………………………………	$80
Dechlorination cost, at 25 cents/kg of sodium metabisulfite Cost of dechlor for 8mg/l of chlorine residual (80kg x 1.34)…	$26

The total cost to chlorinate/dechlorinate 10,000mt of seawater to 8mg/l over a 6-hour period is around $100 USD and requires 70kVA of electric power.
Considering most of the power consumption would be while the ship is at berth while filling the ballast tanks, there should not be any problems in providing power to the hypochlorite generator.

6. Electrichlor Sodium Hypochlorite Generator Model EL1-3B - Description

The Model EL1-3B hypochlorite generator comprises 3 skid-mounted modules (T/R Module, Cell Module & Hypochlorite Module) which, when bolted and connected together, provides a fully functional unit. The transformer/rectifier module houses either a sealed, non-flammable, liquid filled transformer/rectifier unit properly braced for shipboard operation for oil/gas tankers, or an air cooled T/R unit for bulk cargo carriers, and a local control panel cubicle. The cell module is equipped with the electrolytic cells and their accompanying pipework, together with all the controls and instruments necessary for correct operation. The hypochlorite module houses the incoming seawater connection, a hypochlorite degas vessel and the outgoing discharge pumps for delivering the hypochlorite to the ballast tanks.
The hypochlorite generator is equipped with local and remote controls and is capable of being operated from a remote workstation using Modbus protocol. Each cell has an over-temperature alarm and the module is equipped with underflow and overpressure alarms. All equipment is housed in or ASTM-316L stainless steel NEMA 12 cabinets, with all pipework titanium or schedule 80 CPVC depending upon the location; all equipment is selected for a 30-year service life.

7. Ship Board Hypochlorite Generator Installation

7.1 Existing Ships

Due to limited space in engine rooms and machinery spaces, a deck installation is the most effective. The hypochlorite generator is installed ready to operate in either a 20' or 40' cargo container complete with all equipment for immediate operation. Incoming and outgoing pipework flanges are arranged to suit the ship's piping arrangements and power and control entries are also provided to suit the ship's electrical layout. Sufficient space is allowed in a compartment within the container for the storage of chemicals required for operation, so that minimal handling by personnel is necessary.
The container can be located directly on the deck or on stilts to maximize deck space. Properly scheduled, installation and completion can be effected within 24 hours and arranged at any port location during the ship's normal unloading and loading operations.

7.2 New Ships

The hypochlorite generator and auxiliary equipment should be installed in a well-ventilated machinery space either on, or close to the main deck to allow convenient access for the loading of chemicals. The machinery space should also include a ventilated locker of sufficient size for the storage of cleaning and dechlorination chemicals. Electrichlor Inc. can supply layout arrangements suitable for the equipment.

Frequently Asked Questions

1. Question:

   Onsite hypochlorite generators produce hydrogen as a by-product. How is the hydrogen disposed of?

   Answer:

   Hydrogen is produced at the cathode of the electrolytic cell and is transported with the hypochlorite to the storage tank. Hydrogen, one of the lightest gases, does not saturate in water as does air, so it easily disengaged. The storage tank is sized for a 7-minute hypochlorite residence time to allow the hydrogen to completely disengage. Electrichlor hypochlorite generators are equipped with main and standby air blowers to deliver atmospheric air into the top of the sealed storage tank to dilute the hydrogen to a level below the Lower Explosion Level (LEL). It is then exhausted to atmosphere via the exhaust pipework, which is equipped with a hydrogen detector that will give an alarm and shut down the unit if the diluted hydrogen level reaches 4%. A spark arrestor is also provided for installation at the exhaust outlet.

2. Question:

   Some vessels utilize their fuel tanks for ballast water. How does the hypochlorite generator operate under these conditions with fuel oil in the seawater?

   Answer:

   Oily water should never be used for hypochlorite generation. The seawater for chlorination is drawn from the ship's existing seawater cooling water system. There is no seawater/ballast water feed from any ballast tank; this means that it is impossible for oily water to enter the hypochlorite generator. The hypochlorite generator requires about $9m^3$/hr. of seawater, this should be readily available on any existing ship especially as hypochlorite generation would normally be carried out while the ship is berthed.

3. Question:

   Seawater is high in hardness ions, how is a build up of calcareous deposits on the cathode prevented?

   Answer:

   Seawater is high in calcium and magnesium so calcareous deposits will build up on the surface of the cathode over time. However, as Electrichlor electrolytic cells have smooth surfaces with a longitudinal flow between each electrode, the design minimizes deposit build up. This design together with high turbulence in areas where anode to cathode bridging could occur, promotes self-cleaning. While Electrichlor electrolytic cells promote self-cleaning, some acid cleaning is required from time to time. To remove calcareous deposits from the cathode, a 5% hydrochloric acid solution is circulated through the cells. The operating instructions fully describe this function.

4. Question:

   This type of equipment when used in marine applications has been linked to "Stray Current Corrosion". What steps, if any have been taken to mitigate these effects?

Answer:
Stray current corrosion has been a problem with this type of equipment in marine applications due to the nature of the environment in which they have been installed. Electrichlor has thoroughly investigated this problem and recommends that the dc busbars be operated ungrounded. This complies with IEEE 463-1993 and Article 668 of the National Electricity Code, which expressly supports the non-grounding of the dc distribution network for this type of equipment. By allowing the system to float, stray current corrosion cannot occur as there is no path for the flow of any leakage current.

5. Question:
Space on board ship is limited. What are the dimensions of a typical hypochlorite generator for shipboard applications and where should they be housed?

   Answer:
   The Electrichlor EL1-3B is typical for most shipboard applications. The dimensions are as follows:
   Length - 3½ meters, Width – 1.2 meters, Height – 3 meters. Weight during operation – 1200kg
   However, if space limitations are severe, the generator dimensions can be reduced at extra cost.
   The generator or generators should be placed in a non-hazardous area where it can be easily serviced and operated; machine rooms where there is a seawater cooling water source are ideal for the purpose.

6. Question:
What other than occasional acid cleaning is required to service the hypochlorite generator?

   Answer:
   There are no routine service requirements for Electrichlor hypochlorite generators other than to lubricate the pump and motor bearings as required. Generally these would be done on an annual basis.

7. Question:
What guarantees does Electrichlor provide with their hypochlorite generators?

   Answer:
   Electrichlor guarantees each hypochlorite generator against faulty workmanship together with a defects liability period of 18 months from delivery or 12 months from start up. The MMO precious metal coating on the titanium anodes is guaranteed for a period of 5 years at its continuous rated output. Electrichlor further provides a process guarantee for each Electrichlor hypochlorite generator, guaranteeing that it will provide a minimum of 1500mg/l of equivalent chlorine as sodium hypochlorite at the rated output with power consumption less than 4.5kWhrs/kg of equivalent chlorine.

8. Question:
How is the delivery and installation achieved and what instructions are provided for operation:

   Answer:
   Electrichlor provides the generator(s) fully assembled in a shipping container. Delivery can be made to any point around the world as required. Electrichlor does not install the equipment, the buyer will receive the equipment where nominated on the purchase order and arrange the installation. Electrichlor will provide an erection and commissioning engineer to supervise the installation and carry out the commissioning. Generally, the commissioning engineer will train the necessary personnel in the operational procedures and provide an adequate number of Operation and Maintenance Manuals.

9. Question:
Can hypochlorite generators be utilized in freshwater?

Answer:
Yes. However, they require the addition of a premixing brine tank and a supply of sea salt. The sea salt is mixed with the incoming freshwater to produce brine to about 3.5% by weight. The salty-water is then pumped through the hypochlorite generator and the hypochlorite is fed into the ballast water tank.

10. Question:
How much salt is required in a brine system for ballast water hypochlorination in fresh water?

Answer:
To produce saltwater with a salinity level of seawater would require 3.5kg of sea salt for each 96.5 liters of fresh water.
Using the model outlined in Section 5:- To chlorinate 10,000mt of ballast water will require salty water with a salinity level of 3.5%. The overall requirement is 9000 kg/hr (liters/hr) x by 6 hrs x 0.035 = 1890kg of sea salt to chlorinate fresh ballast water to 8mg/l of equivalent chlorine. Using a bulk rate cost for sea salt of 10 cents/kg the added cost is less than US$20, which added to the original cost in Section 5, is approximately US$120/10,000mt of ballast water.

11. Question:
Does the salinity of salted fresh water have to be 3.5% or can it be higher/lower.

Answer:
When a ship is operating in both seawater and fresh water, the flow rates through the hypochlorite generator should be the same to avoid having to carry out flow adjustments and vary operating procedures every time the feed water salinity level is different..

12. Question:
What other models do Electrichlor manufacture and what are their outputs.

Answer:
Electrichlor manufactures hypochlorite generators from 1 to 200kg/hr of equivalent chlorine. The models and outputs for ballast water chlorination are:

Model	Output	Quantity of Ballast Water
EL1-1B	4kg/hr of equivalent chlorine	up to 3333m^3
EL1-2B	8kg/hr of equivalent chlorine	between 3333m^3 and 6666m^3
EL1-3B	12kg/hr of equivalent chlorine	between 6666m^3 and 10,000m^3

The outputs of the larger models are available on request.

13. Question:
We hear about the destruction of the ozone layer. Does the generation of onsite hypochlorite produce any agents that affect this and are there others that are detrimental to the environment?

Answer:
The destruction of the ozone layer is caused by the release of chlorinated hydrocarbons. There are no chlorinated hydrocarbons manufactured or released by the generation of onsite hypochlorination.
The chlorine generated within the electrolytic cell is wholly locked up with the seawater passing through the cell. Chlorine is very miscible in water and is fully adsorbed. This together with 0 residual chlorine ensures that there is no release of any agents detrimental to the environment. The hydrogen released is a lighter than air gas that has no detrimental effect whatever to the environment.

14. Question:
    Could the Electrichlor hypochlorination system be used to eradicate algae that contaminate fuel tanks that are used for ballast both on tankers and in fuel/ballast tanks?

    Answer:
    Yes. Any residual algae will be eradicated especially when pre-chlorinated before ballast water filling.

M.B. Bentley
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Electrichlor Inc.
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