DNV·GL

GUIDANCE NOTE

Safe Installation of Ozone Systems on Ships

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Provide guidance for safe installation of ozone systems on ships.

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Reference to part of this report which may lead to misinterpretation is not permissible.

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1 INTRODUCTION

The purpose of this document is to provide guidance for safe installation of ozone (O_3) systems on-board ships.

Ozone reacts with organic molecules in the water by oxidation, efficiently killing organisms and making ozone systems suitable for water treatment on ships. In fresh water ozone oxidises microorganisms. In marine salt water ozone reacts with bromide ions to hypobromous acid which works as a disinfectant in addition to the initial oxidation.

Due to its reactivity with organic molecules, ozone is toxic for humans at low concentration levels and gives a deteriorating effect on certain materials, like elastomers. It can also have a corrosive effect on metals due to its abilities as an oxidant.

2 FUNCTION OF OZONE SYSTEM

2.1 Ballast water treatment

Ozone is injected into the ballast water to kill organism in the water and thereby gaining compliance with the Ballast Water Management Convention. These are typically large systems with an ozone production capacity of up to 20 000 g O_3/hr. Ozone treatment systems are mainly an option for ships with large ballast water systems, typically with pump capacities above 500 m^3/h. The systems are typically used upon inlet of ballast water.

2.2 Live fish carriers

Ozone systems are used for water treatment between cargo operations to avoid contamination between different fish farms and along coastal areas in general. The oxygen producing part of the system is used to introduce oxygen to the water during transport of fish. Typical ozone production rate is between 500 and 4000 g O_3/hr. The ozone system is typically in use between cargo operations.

2.3 Purse seiners

Ozone systems are used to clean the RSW tanks and piping system after discharging fish ashore. Typical ozone production rate is between 30 and 1000 g O_3/hr. As the systems are used after discharge of fish, the frequency of use may be as low as twice a year, depending on the fishing quotas and ship capacity.

2.4 Other uses

Ozone may also be used in exhaust treatment systems and for treatment of water for ship services. These systems typically have significantly lower ozone production rate than for the other uses as mentioned above.

3 GENERAL LAYOUT OF OZONE SYSTEM

An ozone system is typically made up of the following components:

Air compressor: Supplies air to an air bottle or directly to the oxygen generator.

Oxygen generator: Produces oxygen typically by pressure swing adsorption. Disposes of nitrogen either to the surrounding space or to open air, depending of the amount of by-product nitrogen.

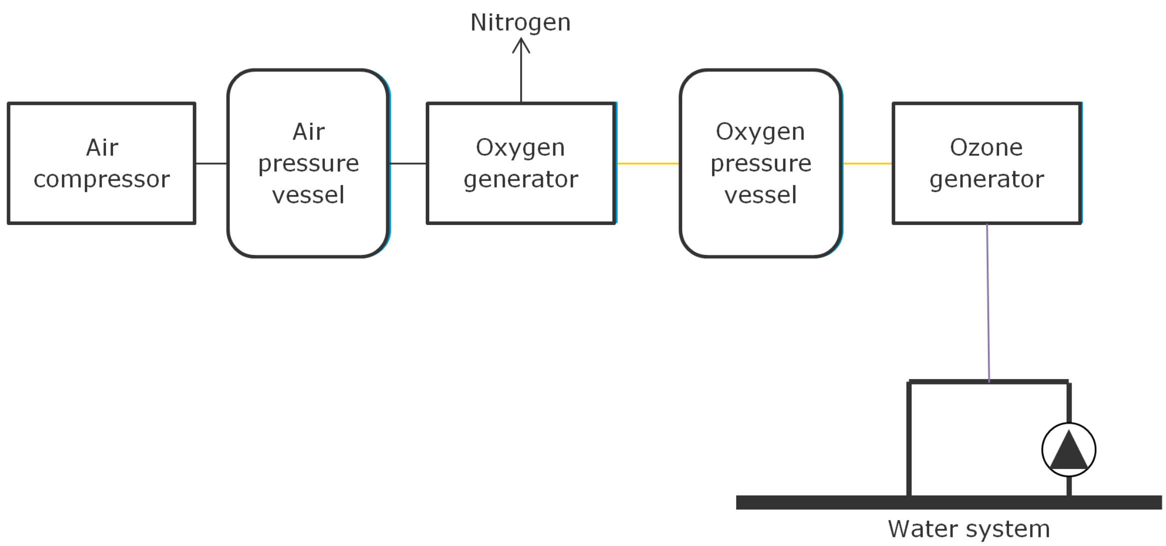
Oxygen bottle: Oxygen is stored in a pressure vessel before supply to the ozone generator.

Ozone generator: Ozone is produced by supplying oxygen into a chamber where high electric voltage splits the oxygen molecules to form ozone. 3 O_2 –> electricity –> 2O_3. Ozone generators are cooled by water or air depending on the size of the system.

Ozone supply: Due to its short half-life, ozone is produced upon demand and cannot be stored. Ozone piping is typically under pressurized compared to surrounding spaces. The ozone injection point to the water system is typically on a side loop to the main water pipe. This side loop is pressurized by a water displacement pump which creates vacuum in the ozone pipe, as if the loop was an ejector pump.

Safety and control system: Ozone systems on ships are typically fully automated. Leakage detection is done by gas detection and/or vacuum pressure monitoring. Automatic shutdown can be triggered by signals from leakage detection, the connected water systems or the ventilation system in the space. Ozone supply can be shut down by automatic closing of a valve on the supply pipe or by shutting down the ozone generator. Depending on the size of the systems, ozone is purged either by vacuum injection into the water pipe and sequential shutdown of valves, to open air by oxygen purging, or via an ozone destructor. The system is commonly purged with oxygen to prevent build-up of moisture. The systems are commonly equipped with visible and audible alarms.

Figure 3-1 Typical layout of ozone system



4 PHYSICAL EFFECTS ON HUMANS

The following table presents the toxic effects of ozone at different ppm levels, along with other notable entries like common maximum exposure limits.

Table 4-1 Physical effects on humans

Concentration [ppm]	Duration of exposure	Effect*	Other notables
0.01			Odour threshold
0.1		Minor eye, nose and throat irritation	Maximum 8hr exposure limit (UK, US)
0.10-0.25	2-5hrs	Headache, dry couch and some reduction in lung function	
0.2			Maximum 15min exposure limit (UK)
0.3	2hrs	Reduction in lung function during moderate work for all persons	
>0-6	2hrs	Chest pain	
1.0	1-2hrs	Lung irritation/couching; severe fatigue	
>1.5	2hrs	Reduced ability to think clearly; continuing cough, extreme fatigue may last for two weeks; Severe lung irritation and pulmanory edema (fluid build-up)	Pulmanory edema may have delayed effect
1<ppm<10		Possible coma, and as above. Severe pneumonia may occur at higher levels	
11	15 minutes	Rapid unconsciousness	
50	30 minutes	Fatality expected**	

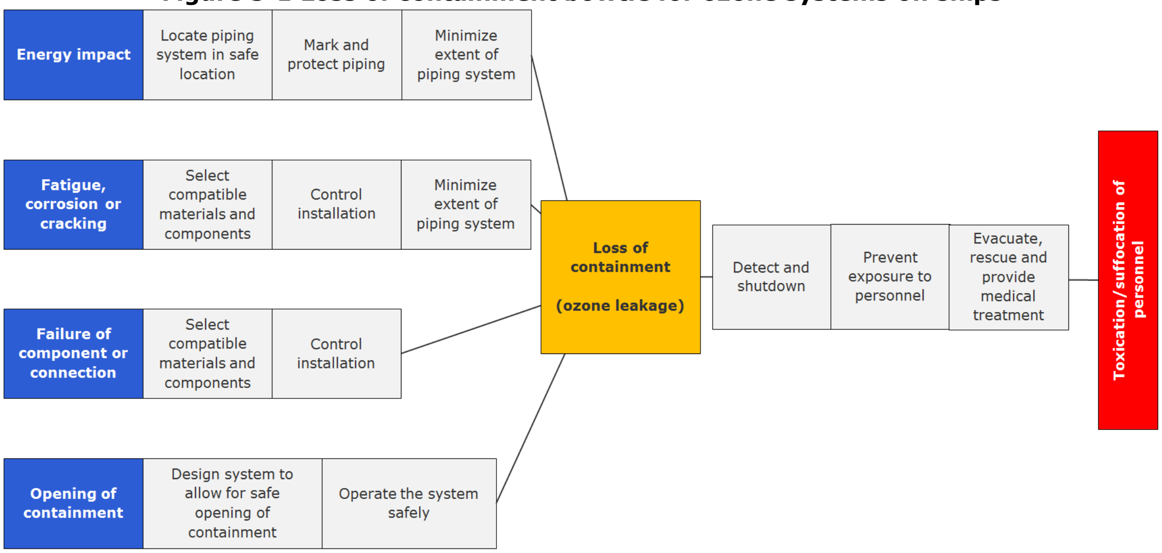
*Based on observations from actual exposures, except from **
**Based observations on laboratory animals

Source: /5/WorksafeBC 2006, Ozone Safe Work Practices

5 MAPPING OF RISK

The risks of using ozone on board a ship are mapped according to potential accident scenarios as follows:

Figure 5-1 Loss of containment bowtie for ozone systems on ships



The bowtie consists of the following elements:

5.1 Top Event

Located in the centre of the bowtie: A point in time which describes the release or loss of control over a hazard. In this case: Loss of ozone containment.

5.2 Causes

Located on the far left of the bowtie, marked blue: An initiating event or situation that can lead directly to the Top Event, but passing through potentially several Prevention Barriers.

5.3 Consequences

Located on the far right of the bowtie, marked red: Possible undesired outcomes that flow directly from the Top Event, but passing through potentially several Mitigation Barriers.

5.4 Barriers

Marked grey. Prevents or influences a real chain of events in an intended direction.

- Prevention barriers (left side) should have the capability to terminate an event.
- Mitigation barriers (right side) may only be capable or reducing the magnitude

6 GUIDELINES FOR SAFE INSTALLATION

The following chapter consists of guidelines for safe installation of ozone systems on board ships. The guidelines are formulated as requirements, this is merely as preparations for future adaptation into class rules.

6.1 General

1. The requirements are safety measures accepted by DNV GL as providing a minimum quality to the safety barriers. Other safety measures that provide an equivalent level of safety may be accepted upon special consideration.
2. The requirements are valid for ozone systems on ships where the worst case leakage in an enclosed space may result in ozone concentrations of above 0,1 ppm.

6.2 Definitions

1. *Primary containment*: A space containing ozone, i.e ozone pipes and ozone generator.
2. *Secondary containment*: A space containing ozone piping, e.g an ozone production room or the annular space in double walled piping.
3. *Ozone leakage sources:* Ozone generator, flanges, valves, welds etc

6.3 Prevention barriers

6.3.1 Locate piping system in safe location

1. Ozone piping systems shall be located in safe locations with regards to mechanical damage from dropped or rolling objects.

6.3.2 Mark and protect piping

1. Ozone pipes shall be marked to visually separate them from other piping systems.
2. A signboard shall be permanently fitted in the space containing ozone piping stating that heavy lifting, implying danger of damage to the ozone pipes, shall not be done during ozone operation.

6.3.3 Minimize extent of ozone piping system

1. The extent of ozone piping shall be minimized as far as possible in order to reduce the possible leakage points.
2. Flange connections on ozone piping shall be minimized as far as possible in order to reduce the possible leakage points.

6.3.4 Select compatible materials and components

1. Ozone piping shall be of austenitic stainless steel or of a material with similar corrosion resistant properties. Special consideration shall be given to connections between stainless steel ozone piping and mild steel piping.
   Note:
   Elastomers are generally not compatible with ozone.

6.3.5 Control installation

1. The ozone piping shall be tightness tested in the presence of the surveyor after installation on board.
2. All required functions of the safety and control system shall be tested in the presence of the surveyor after installation on board.

6.3.6 Safe opening of containment

1. It shall be possible to safely gas-free the ozone and oxygen system prior to opening the containment.
2. Outlets for purging of the ozone system shall be at safe locations with regard to air intakes for other ventilation systems on the ship.

3. Purging or venting of the ozone piping systems shall not lead to hazardous ozone concentrations on deck or in enclosed spaces.
   Note:
   Hazardous concentrations may be avoided by diluting the ozone or installing an ozone destructor.
4. Procedures for opening of containment shall be described in detail in the operational manual required in chapter 6.3.7.

6.3.7 Operate the system safely

1. An operational manual for the ozone system is subject for approval. The manual shall be kept on board the ship and shall as a minimum contain the following:
   a. General description of the system
   b. Ozone generation and supply system piping and instrumentation diagram
   c. Procedures for starting up the system
   d. Procedures for shutting down and gas freeing the system
   e. Procedures for opening of containment.
   f. Entry and evacuation procedures for the spaces containing ozone piping systems
   g. Procedures for calibration or changing of sensors
   h. Procedures for periodic inspections and tightness testing.
   i. Use of personal protective equipment
   j. Medical treatment procedures for intoxication and suffocation
2. Portable ozone and oxygen gas detection shall be provided. Oxygen gas detection is not required on systems where worst case leakage of oxygen, nitrogen or ozone cannot lead to hazardous concentrations with regards to suffocation.

6.4 Mitigation barriers

6.4.1 Detect leakage and shutdown system

1. All possible leakage sources in the ozone piping system shall be covered by a minimum of two independent means of ozone leakage detection.
   Note:
   Fixed ozone gas detectors close to possible leakage sources and pressure monitoring are accepted methods for leakage detection. A combination of the two methods is accepted.
2. Fixed ozone gas detectors shall cover all possible leakage sources. Gas detectors shall as a minimum be placed close to the ozone generator and the ozone injection point.
3. The sensors or sampling suction points for ozone gas detectors shall be located where an ozone leakage is most likely to be sensed first.
   Note:
   Due regard shall be taken to the relative density of the gas as well as to the ventilation flow.
4. If double walled ozone piping is installed, fixed ozone gas detectors shall be located at the ventilation outlet from the annular space in the double walled piping.
5. Ozone gas detectors shall have a set point of 0,1 ppm ozone.
6. Ozone piping systems shall be fitted with automatic shut-off and purging functions.
7. An emergency stop button shall be located where the ozone system is operated as well as locally within and outside the accessible spaces containing ozone piping.
8. The alarm shall be both acoustic and optical and the signals shall be given within the accessible spaces containing ozone piping and at such locations that crew members attending to an alarm will not be led to entering a space possibly containing leaked ozone.
9. The following signals shall lead to alarm, automatic shutdown and purging of the ozone system:
   a. Ozone leakage detection
   b. Emergency stop buttons
   c. Failure of ventilation system. Applicable according to chapter 6.4.2.2 Alt.2
   d. Failure of connected water system to which the ozone is injected. Applicable according to chapter 6.4.2.

6.4.2 Prevent exposure to personnel

1. Leakage from the primary containment shall not directly lead to intoxication of personnel.
2. The following safety measures are accepted to satisfy this functional requirement. A combination of the three different alternatives may be accepted for different parts of the piping system.
   <u>Alt.1:</u>
   a) The ozone piping shall be designed with a dedicated secondary containment.
      Note:

Alternative 1 is typically for ozone piping with over pressure compared to adjacent spaces, typically the ozone generator or pressurized ozone supply piping.

b) The secondary containment shall be gastight towards other enclosed or partly enclosed ship spaces.
c) The ventilation system for the secondary containment space shall be separated from other ventilation systems.
d) All ventilation outlets from the secondary containment space shall be at safe locations with regard to air intakes for other ventilation systems on the ship.
e) Ventilation openings in the secondary containment space shall be strategically located in order to ensure an efficient air flow in the space.
f) The secondary containment space shall not be designed for passing between other ship spaces.
g) If there are doors for entering a secondary containment space, they shall be self-closing.

Alt.2:

a) Ozone piping with over pressure compared to adjacent spaces may be designed without a secondary containment. The main condition is that it can be shown by calculation that the worst case leakage scenario does not cause ozone concentrations above 1 ppm.
   Note:
   The calculation shall as a minimum take into consideration the worst case leakage rate, the volume of the enclosed space, the ventilation capacity and time delays related to leakage detection and automatic shutdown. Calculations that assume even distribution of leaked ozone are generally accepted for small and well ventilated spaces. More advanced are required for large spaces or spaces of irregular shape or layout.
b) Loss of ventilation in the space containing the ozone system shall lead to automatic shutdown of the ozone system.

Alt.3:

a) The ozone piping system shall be designed in such a way that the ozone is under-pressurized compared to adjacent spaces.
b) Loss of under pressure shall lead to automatic shutdown of the ozone system.

3. Ozone pipes shall not pass through accommodation or service spaces.
4. Safety measures shall be in place to prevent supply of ozone to empty water systems.
5. Nitrogen rich waste stream shall be vented to open air. Disposal of nitrogen to an enclosed space may be accepted if it can be shown by calculation that the amount of disposed nitrogen does affect the health of present personnel.
6. A signboard shall be permanently fitted on doors or other access points to spaces containing ozone warning that an ozone system is installed.

6.4.3 Evacuate, rescue and provide medical treatment

1. The operational manual required in 6.3.7 shall contain the following:
   a) Evacuation procedures for ozone contaminated spaces
   b) Use of personal protective equipment
   c) Medical treatment procedures for intoxication and suffocation
2. At least two sets of air breathing apparatuses with spare air bottles shall be available onboard. The breathing apparatuses may be the same as those required for other purposes, provided the ship is equipped with an air compressor for recharging the air bottles.
3. At least one resuscitator shall be kept on board for medical treatment.
4. Ozone protection masks to be used for rescue shall be stored outside entrances to spaces containing ozone piping.

APPENDIX: EXAMPLES OF OZONE LEAKAGE CALCULATIONS

The following simplified analyses calculate the resulting ozone ppm levels in a ventilated and enclosed compartment in which an ozone leak has occurred.

The analytic equations are based on the assumption that the gas is perfectly mixed after it leaks out. Close to the leak, the ppm can be significantly higher than the rest of the area. If the designated space for the equipment/piping is of large size, the dispersion of the leak would be localized (e.g. local circulation of the air flow, or stagnant zones) and therefore this assumption would be non-conservative and the tool would underestimate the local concentration level significantly, and hence give wrong indication of how the ventilation should be

More advanced calculation tools such as computational fluid dynamics calculations are available and offered from DNV GL Maritime Advisory.

The examples are based on existing systems and ship designs. Examples are given for a general ballast water treatment system in a steering gear room, an ozone production room on a live fish carrier and for a purse seiner.

The variables are as follows:

- Ozone production rate [g/hr]
- Leakage rate [percent of production rate]
- Volume of compartment
- Ventilation rate

Limitations to calculation:

- Natural decay of ozone is not accounted for.
- An emergency ventilation system is not included

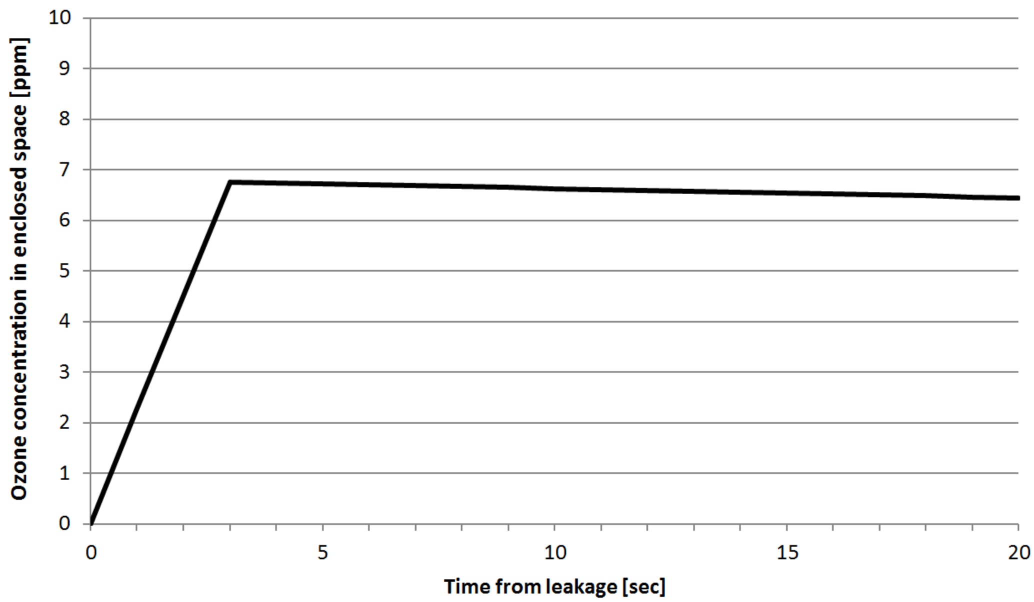
Assumptions:

- Even distribution of leaked ozone
- Functional leakage detection causing shutdown at 0,1 ppm ozone concentration
- 2 second delay from leakage detection to automatic shutdown of the system

Ballast Water Treatment

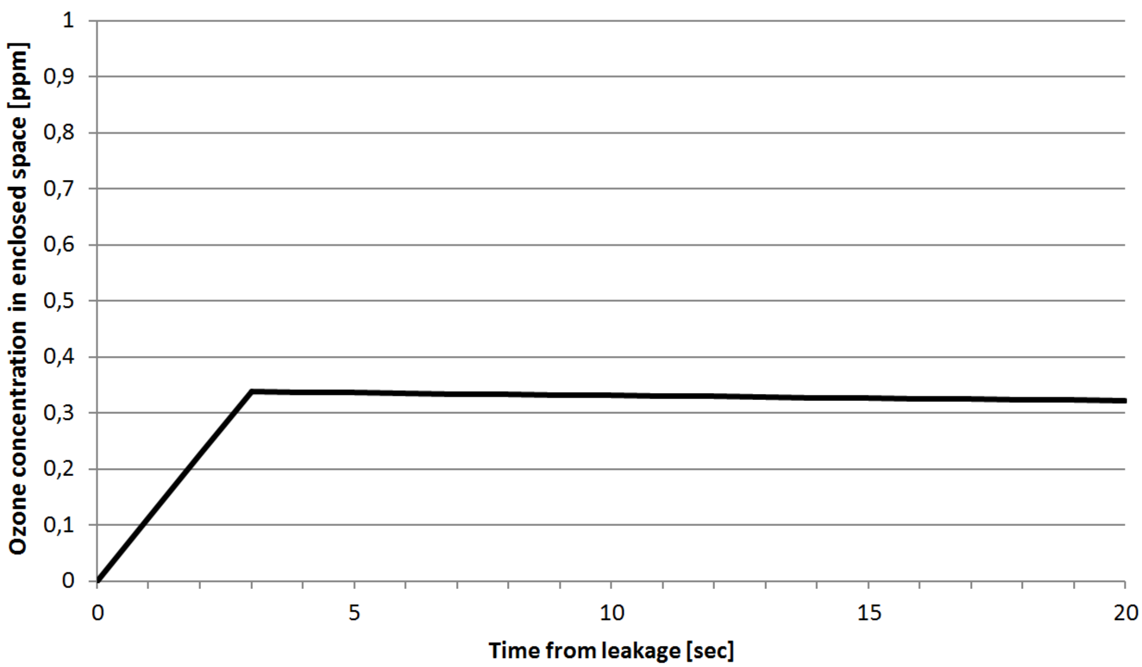
Typical steering gear room. Large system. Large leak.

Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	16 000
Leak rate	[%]	100
Volume of space	[m^3]	1 000
Ventilation capacity	[air changes/hr]	10



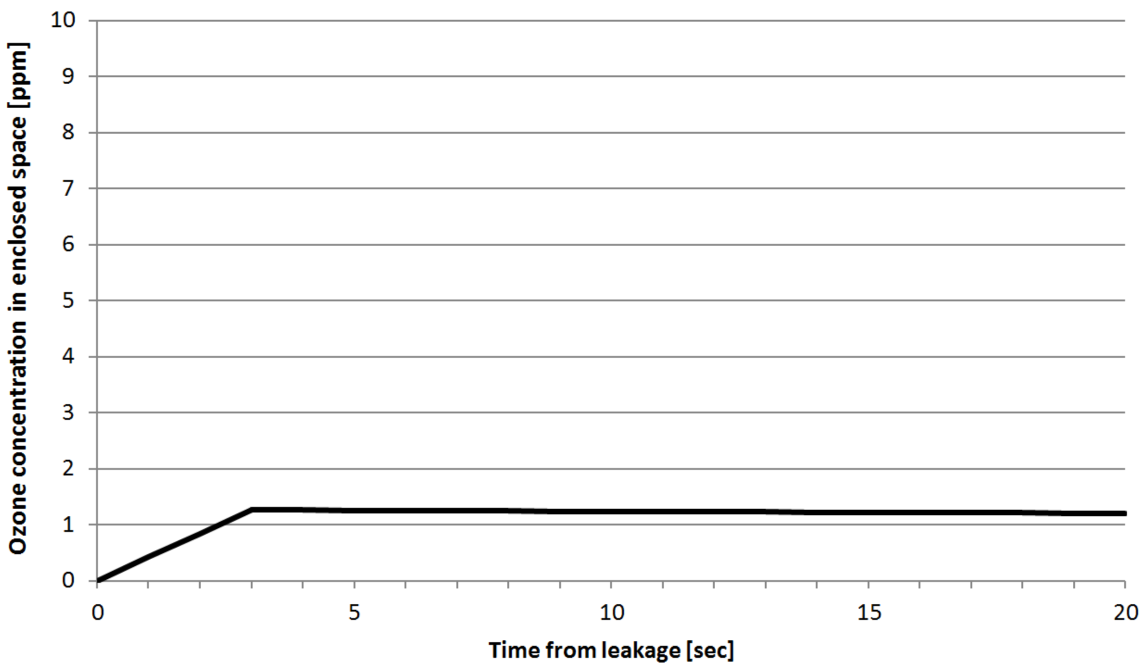
Typical steering gear room. Large system. Small leak.

Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	16 000
Leak rate	[%]	5
Volume of space	[m³]	1 000
Ventilation capacity	[air changes/hr]	10



Typical steering gear room. Small system. Large leak.

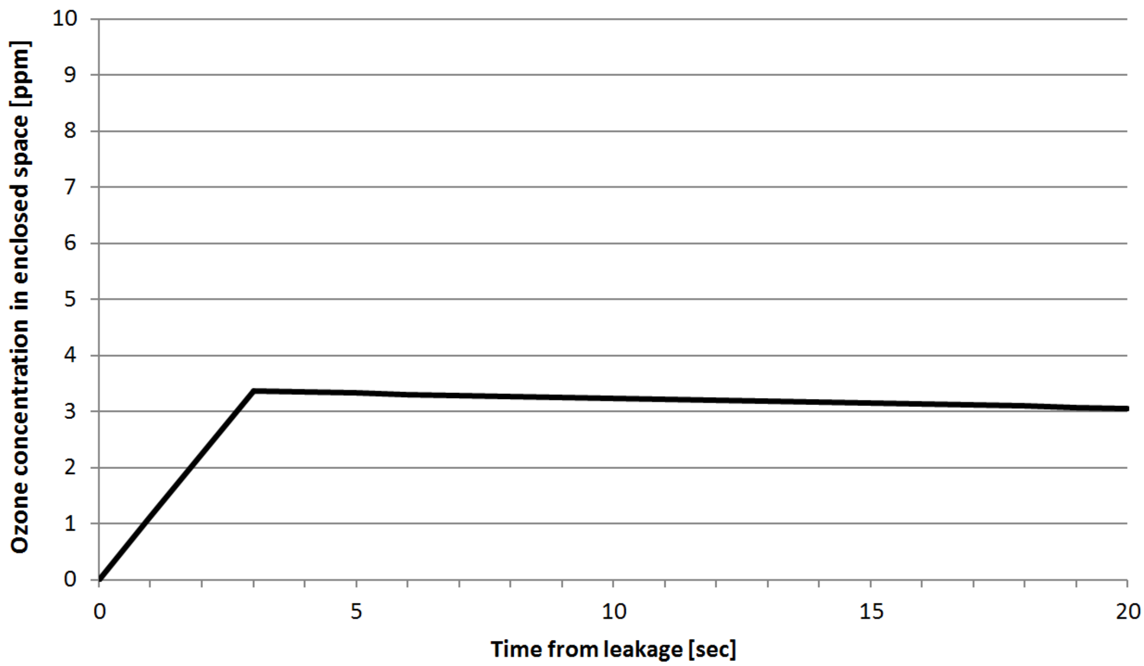
Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	3000
Leak rate	[%]	100
Volume of space	[m^3]	1 000
Ventilation capacity	[air changes/hr]	10



Live Fish Carrier

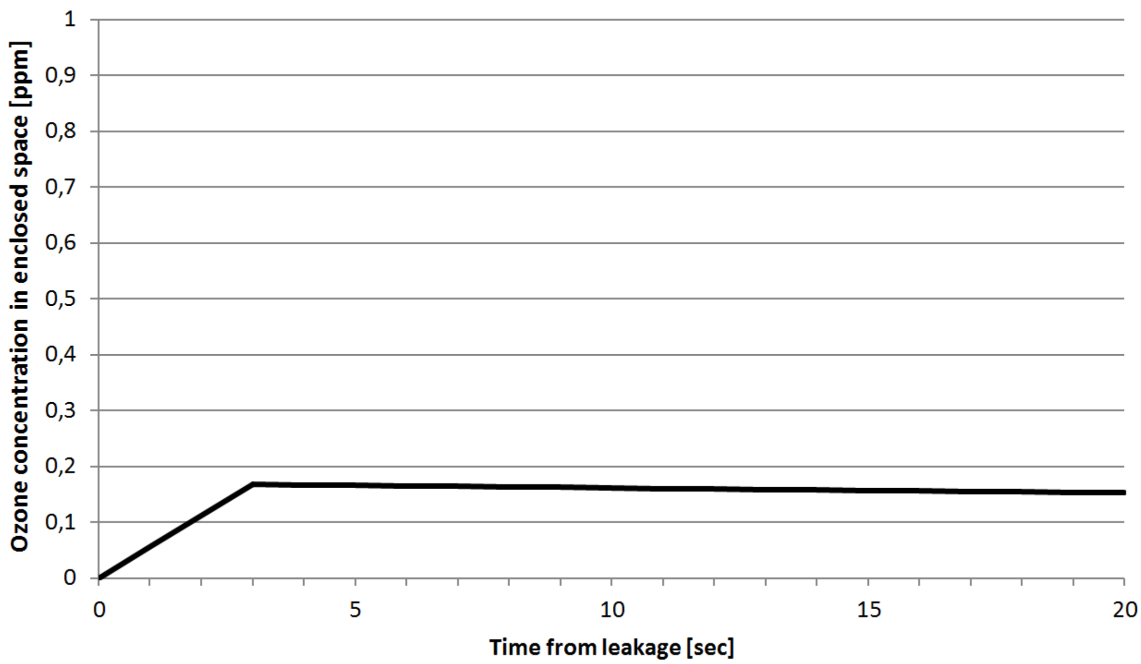
Typical ozone production room. Large leak.

Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	4 000
Leak rate	[%]	100
Volume of space	[m^3]	500
Ventilation capacity	[air changes/hr]	20



Typical ozone production room. Small leak.

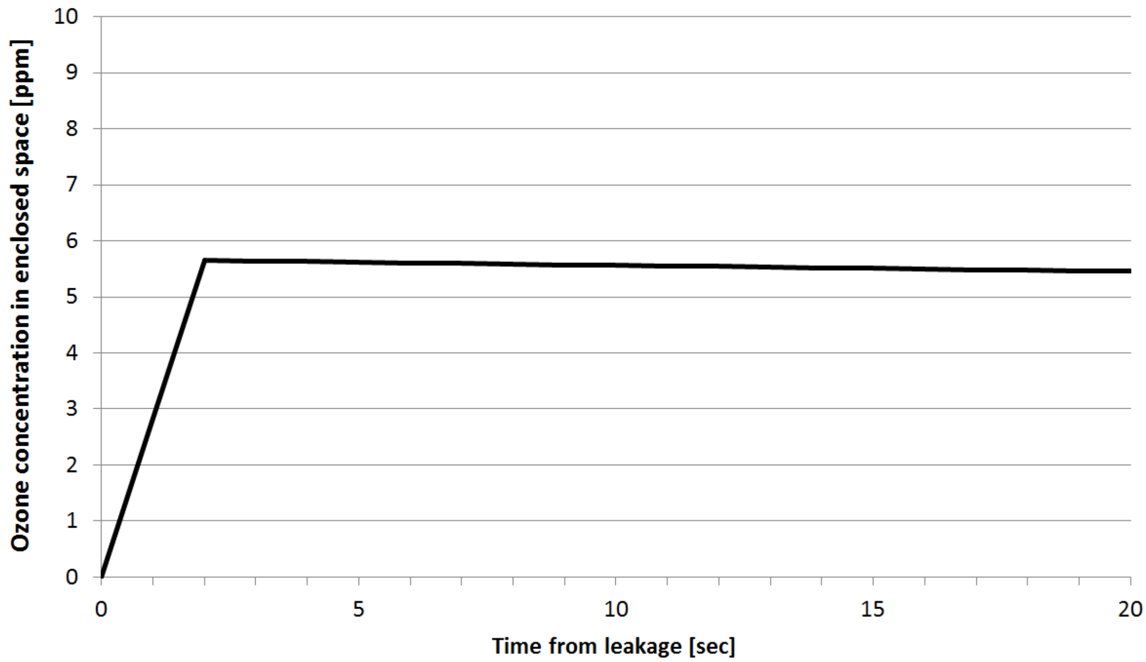
Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	4 000
Leak rate	[%]	5
Volume of space	[m³]	500
Ventilation capacity	[air changes/hr]	20



Purse Seiner

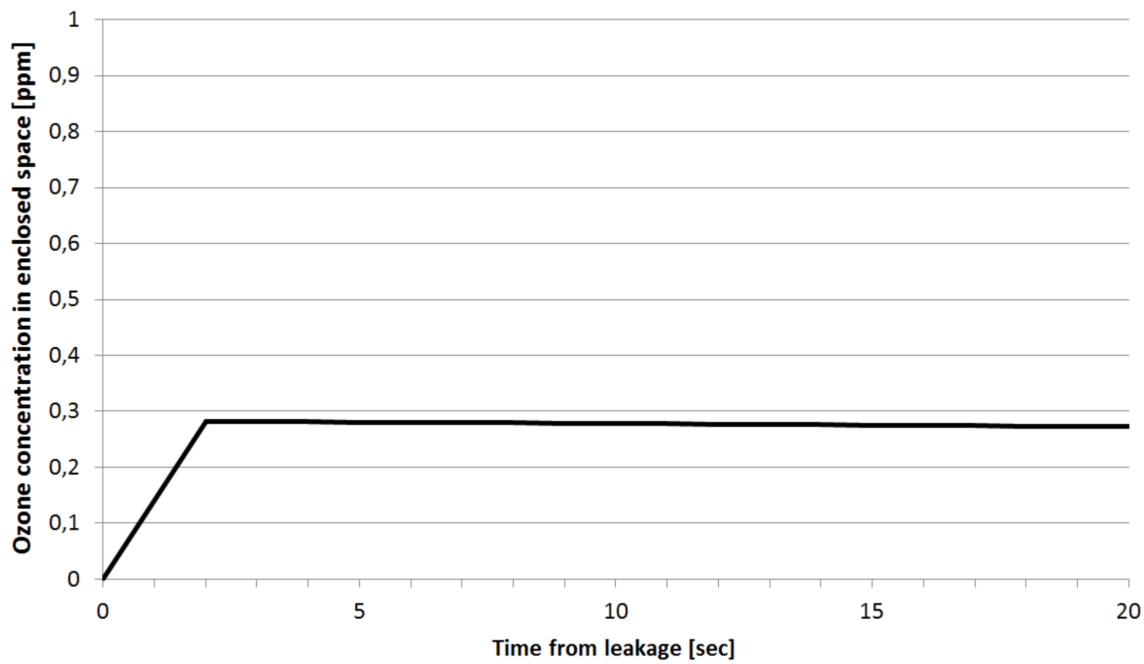
Typical space with ozone piping. Large system, large leak.

Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	1 000
Leak rate	[%]	100
Volume of space	[m^3]	50
Ventilation capacity	[air changes/hr]	7



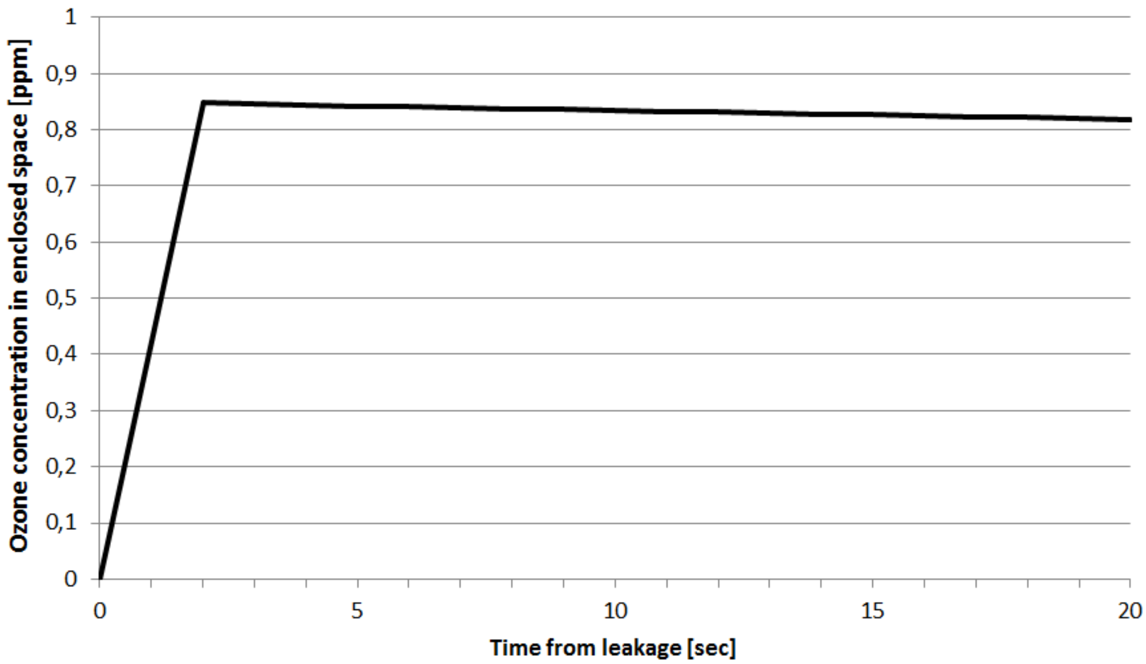
Typical space with ozone piping. Large system, small leak.

Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	1 000
Leak rate	[%]	5
Volume of space	[m^3]	50
Ventilation capacity	[air changes/hr]	7



Typical space with ozone piping. Small system, large leak.

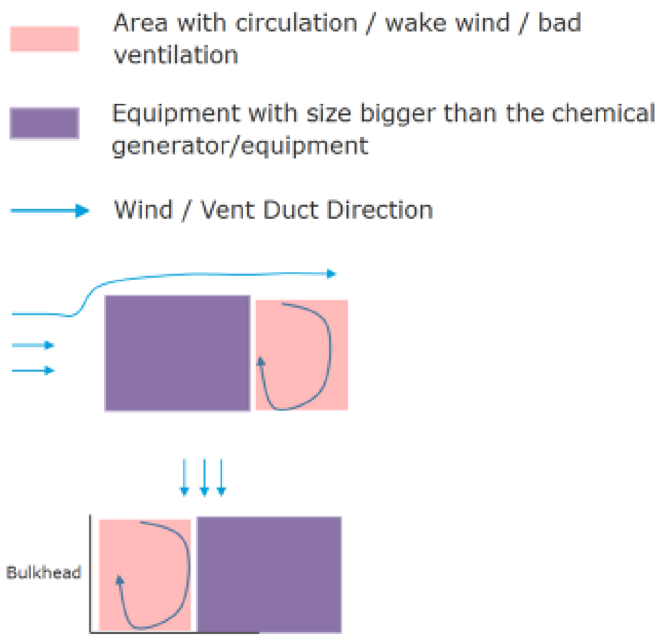
Input parameter	Unit	Value
Ozone production capacity	[gr/hr]	150
Leak rate	[%]	100
Volume of space	[m^3]	50
Ventilation capacity	[air changes/hr]	7



APPENDIX: GENERAL GUIDANCE FOR LOCATION OF OZONE EQUIPMENT IN ENCLOSED SPACES

Possible leakage points should as far as possible to be located close to extraction fans so that any leakage will immediately be extracted from the space

Ozone piping should as far as possible be located in a space where sufficent air flow is provided.



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