Selecting a Suitable Disinfectant for your Hyperbaric Chamber (2025)

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OBJECTIVES

At the completion of this activity, the participant will be able to:

- Differentiate between cleaning, disinfecting, and sterilizing
- Select appropriate cleaning/disinfecting products
- Explain the effect of other disinfection processes

INTRODUCTION

Selecting an appropriate, safe, and hyperbaric chamber friendly disinfectant is often mistakenly assumed as the most important action in controlling the spread of any harmful pathogens. Effective infection control requires all the following steps:

- Identify the pathogens[1] of concern
- Avoid any physical contact with potentially infected surfaces or people
- Isolate suspected zones where pathogens might be present
- Control access to such isolated areas, ensuring anyone entering the area is suitably informed, instructed, and wearing appropriate personal protection equipment
- Quantify the life cycle of the pathogens
- Clean then disinfect infected surfaces and (where applicable) the breathing environment
- Dispose of all contaminated cleaning waste products properly
- Monitor compliance and effective control of the process

This article will focus on the selection of an effective, suitable disinfectant using a comprehensive list of criteria to ensure applicability in the hyperbaric chamber. Other means of destroying pathogens and additional aspects of the hyperbaric environment will be discussed.

DEFINITION OF TERMS

It is important to understand common terminology when it comes to identifying products and processes. While some users interchange terms, they each have distinct meanings.

Table 1 provides generic descriptions of each of the terms, the effect on pathogens, and the applicable processes generally used.

Table 1 Definition of terms (Rutala, 2008)

Term	Effect	Applications & examples of methods
Cleaning or Decontamination	Removes gross surface matter. Essential step in ensuring effective sanitization or disinfection, as it exposes the actual surface being addressed. Especially relevant with UV disinfection.	Physical removal of surface debris by chemical and/or mechanical means. Achieved using agitated, mechanical means on all surfaces (wiping, scraping, scrubbing), with or without a suitable detergent.
Sanitization	Reduces pathogen count to safe levels. Some resilient pathogens may survive.[2] In some cases, products are actually disinfectants but have not been registered with the US Environmental Protection Agency (EPA).	Porous and non-porous surfaces. The only practical means of decontaminating bedding, clothing and other porous materials. Achieved using chemicals, pasteurization, or UV light
Disinfection	Destroys almost all pathogens, excluding some bacterial spores.	Suitable for hard, non-porous surfaces only. Achieved using chemicals, pasteurization, or UV light
Sterilization	Destroys practically all surface pathogens.	All unsealed surfaces Achieved using steam, heat, chemicals, gas, plasma, or radiation.
Sanitation	Hygienic disposal of waste materials.	Prescribed waste management of chemicals and application materials.

The terms ‘sanitizer’ and ‘disinfectant’ describe products and processes with a similar effect on pathogens. Both are categorized as pesticides[3]. In some cases, the only difference between a sanitizer and a disinfectant is EPA endorsement as a disinfectant. They might have identical active ingredients and effects, but the term ‘disinfectant’ may not be used without EPA endorsement. Regardless of the term used, the user must ensure that the selected product yields the appropriate effect for their application. In this article the term ‘disinfectant’ includes disinfectants and sanitizers unless otherwise stated.

THE HYPERBARIC ENVIRONMENT

When selecting a product and/or application process, the constraints of the environment must be considered. The hyperbaric environment may include all the following constraints:

- Non-metallic and porous surfaces, typically applicable to bedding, pillows and mattresses.
- Probability of close human physical contact due to confined spaces, especially where multiple patients are seated on a bed/bench rather than on individual seats.
- Acrylic windows are particularly vulnerable to some of the most effective disinfectants, such as those with alcohol as the active ingredient. Acrylic tubes on monoplace chambers are especially vulnerable to chemical damage.

- Complex internal configurations, such as mountings for seats, and the space under deck-plates (sub-floor or crawl space present in some chamber designs). Some surfaces may be inaccessible during routine cleaning and require disassembly or labor-intensive removal to access effectively.
- Lack of suitable access to effectively reach, and to then remove any disinfecting or cleaning products (such as where flushing may be required).
- Varying equipment manufacturer requirements based on specific materials used.
- Varying hospital policies for infection control, including using products not suited for the hyperbaric environment or associated equipment

PRIMARY RESOURCES

In the first step of an evaluation, essential information (i.e., identifying and describing relevant pathogens) is available from the US Center for Disease Control (CDC) or your country's equivalent.

The CDC is responsible for studying infectious diseases. They may have guidance on the following: presence of a specific pathogen, active ingredients in disinfecting products, minimum concentrations, suitable processes, and applicable reference materials.

Each country's version of an environmental protection agency (e.g., US EPA, European Chemicals Agency - ECHA) typically provides information on chemical products that can be used for disinfection. They require suppliers or manufacturers to list or describe the following: pathogens controlled, active ingredients in the products, types of surfaces that can be disinfected, and application processes. The registration or listing process requires the supplier/manufacturer to provide a great amount of useful detail, which can usually be retrieved from the product listing pages. The relevant information is usually obtained by searching the EPA, Chemical Abstracts Service (CAS) or Pesticide Chemical (PC) websites, using the respective registration numbers to retrieve the product, active ingredient(s), applications instructions, manufacturer, or supply entity.

EPA, CAS, and PC registration numbers (and other information on products) can be found at the following websites:

EPA Pesticide search page

https://www.epa.gov/safepestcontrol/search-registered-pesticide-products

ECHA Biocide Article 95 list

https://echa.europa.eu/information-on-chemicals/active-substance-suppliers

During the SARS CoV2 pandemic, the EPA produced a specific list of registered products effective in inactivating the virus. The EPA created a "List N Tool" hyperlink to focus on this specific pathogen. It can still be accessed from this website:

https://cfpub.epa.gov/wizards/disinfectants/

National organizations often respond to specific infectious diseases in this manner.

Product Safety Data Sheets (SDS), previously called MSDS, provide basic safety information for each chemical product, including hazardous and harmful materials, fire and associated risks, and appropriate waste disposal.

Product and technical data sheets (PDS, TDS) and product package application instructions, provide information on targeted pathogens, dosage, concentration, application instructions, soak (wetted) times, and additional safety instructions.

CRITERIA FOR SELECTING DISINFECTANTS

Hyperbaric facility users often feel bewildered when the time comes to make a change to a product, such as when the hospital dictates something different, or where their existing products are no longer available. In some cases, countries or local jurisdictions may prohibit certain chemical compounds from being used.

Hyperbaric chamber manufacturers (especially those located in the US) may be prescriptive in the products they allow to be used. Often, these products are only available in the country of manufacture. Even in those cases, hyperbaric facility management is still responsible for ensuring compliance with other considerations – such as effectiveness on newly identified pathogens, materials allowed in the chamber, harm to people and materials, and applicable healthcare facility requirements.

The following 14 criteria should enable the reader to navigate the essential steps in selecting an effective, safe, practical, and available product.

Table 2: Criteria for selecting disinfectants

Step	Criterion	Notes	Resources
1	Effective for the spectrum of pathogens	Include bacteria, fungi, viruses, spores, parasites, and protozoa	CDC, EPA
2	Human compatibility	Harm from ingestion, inhalation, or contact (skin, mucus, eyes)	SDS, Package instructions
3	Odor during application and residual odor	Acceptable limits vary in terms of compound concentration (ppm_v)	SDS, TDS, NIOSH[4]
4	Staff health and safety	Exposure during application, removal and waste disposal; PPE[5] requirements	SDS
5	Residue	Non-toxic, non-flammable, non-harmful to materials or people	SDS
6	Oxygen safety	Exposure of any residual amounts to oxygen enriched environments (≥ 23.5% O_2)	NFPA[6]
7	Fire safety	Potential ignition and combustion during application and from residual chemicals	SDS
8	Material compatibility	Non-corrosive, non-degrading, and non-damaging to acrylic materials	SDS, PVHO-2
9	Hyperbaric and equipment manufacturer requirements	Acceptable to the manufacturer (where stated in manuals or specifications)	Product manuals
10	Application method	Ease and practicality of use	EPA, ECHA PDS, TDS
11	Application time	Soak time, drying time	EPA, ECHA, PDS, TDS

12	Waste disposal	Available means or services for disposal	SDS
13	Availability	County, state/province, or regions	Local statutes
14	Price	Affordability (note dilution requirements which affect economy of use)	Commercial considerations

NOTES ON DISINFECTANTS

The following information describes additional considerations when selecting a disinfectant product:

- Almost all disinfectants are suitable for hard, non-porous surfaces only.
- The most commonly used, and generally acceptable product group for hyperbaric chambers, are quaternary ammonium compounds. A primary restriction is the proper and safe use and disposal of all waste products containing the active ingredient.
- Antiseptic products (labeled and sold as such) are not considered suitable disinfectants. They are primarily used to prevent infection in humans and animals. Even though they reduce/prevent propagation of bacteria, fungi, or viruses in wounds, products containing iodine, peroxides, isopropyl and ethyl alcohol, and antibacterial compounds should generally not be considered as disinfectants for inanimate surfaces.
- Alcohol-based products must contain less than 4% by volume to avoid harming acrylic windows. (PVHO-2, 2019) The required concentration to achieve adequate disinfection is at least 20%.
- Bleach (active ingredient: sodium hypochlorite or NaClO) is commonly used in disinfection. The correct, effective concentration of the active ingredient using regular household bleach (which typically contains around 5% NaClO), is achieved by adding 20 ml of household bleach to one liter of clean water (1/3 cup to 1 gallon). This will produce a solution containing 2% household bleach with a concentration of 1,000 ppm_v NaClO. The CDC requires this 2% solution for a contact time of at least 1 minute, then flush with clean, potable water. Surfaces should be left to dry normally. At this concentration, residual odor on hard surfaces should be minimal. Note that this only applies to hard surfaces. (CDC, 2019) (DoH, 2014)

  While highly effective, bleach is not a suitable option for daily cleaning unless the area is well ventilated overnight. It may be difficult to adequately ventilate the inside of a hyperbaric chamber, particularly in the bilge of a multiplace chamber.

  <u>What makes bleach harmful?</u>

  The smelly and dangerous component of bleach is chlorine (Cl_2). In its natural state, chlorine is a gas. To have it in a liquid state, we use a hypochlorite ion. This ion attaches to a pathogen and inactivates/destroys it.

  Chlorine has an effect on humans at concentrations higher than 0.002 ppm_v. Irritation occurs at 1 ppm_v. NIOSH limits short term exposure to less than 0.5 ppm_v.

  It is a commonly held belief that a 10% solution (5,000 ppm_v NaClO) is necessary for disinfection. A concentration this high is usually excessive, potentially harmful to material surfaces, and leaves a strong, unacceptable residual odor. The product EPA registration will indicate the appropriate concentration where higher than 1000ppm_v NaClO is necessary.

PVHO-2 allows a concentration of up to 15% household bleach (7,500 ppm_v NaClO) to be used on acrylic windows. (PVHO-2, 2019)

Calcium hypochlorite ($CaClO_2$), an alternative source of chlorine for swimming pool sanitization, is a potential alternative to bleach. It is generally available but requires careful examination of each product to determine the applicable amount of active ingredient required. Typical pool chlorine concentrations are between 1 - 3 ppm_v, clearly inadequate for disinfection.

Sodium bromide (NaBr) is another alternative to bleach, but while the disinfectant properties are similar, it is more expensive and not as readily available as household bleach.

- Hydrogen peroxide (H_2O_2) requires a concentration of 0.5% - 3% to effectively disinfect surfaces (according to EPA). 3% H_2O_2 can be used for fabrics. (Neely, 1999) PVHO-2 limits this active ingredient to less than 20%.
- PVHO-2 mentions only 3 suitable disinfecting product ingredients: NaClO ≤15%, aqueous chloride dioxide (ClO_2) ≤2% (a bleaching compound), and H_2O_2 ≤ 20%. This is partly based on products available when the code last considered these, and partly due to avoiding an impossibly long list of products, which either become unavailable or are removed between revision cycles. Any products selection must therefore take careful account of active and other ingredients that could potentially harm acrylic materials. Consultation with hyperbaric chamber manufacturers and/or acrylic manufacturers is an essential part of product selection where contact with acrylic windows is likely to occur.

ALTERNATIVE OR SUPPLEMENTARY DISINFECTION PROCESSES

The following alternative processes are used for surface disinfection, especially where (mechanical) cleaning is performed prior to the application of the disinfection process.

Ultraviolet (UV) Disinfection

UV high-energy radiation is a well-advertised disinfection process, and commonly used in healthcare facilities. It is necessary to understand how this works to avoid some of the inaccurate statements made in the marketing of UV generating devices.

UV radiation as experienced on earth is broadly classified into three wavelength bands, with the primary criteria being the biological effect:

- UVA with a wavelength range of 320 - 400 nanometers (nm). UVA reflects off certain surfaces and can also penetrate the skin down to the hypodermis in humans. It causes tanning, burning and aging, as well as some skin cancers, but is regarded as relative benign in limited doses. Some refer to this as the *aging ray*. It is also benign to acrylic windows. UV light in this wavelength range is used to detect hydrocarbons and other materials that fluoresce.
- UVB with a wavelength of 280 - 320 nm. UVB does not easily reflect or penetrate surfaces, and the radiation energy is absorbed by the surface it strikes. The effect on humans is the burning of the outer layer of the skin. It is mutagenic and a cause of skin cancer. Some refer to this as the *burning ray*. Most of the UVB emitted by the sun is absorbed by the ozone layer.
- UVC with a wavelength of 100 - 280 nm. UVC does not reflect and is entirely absorbed by the outer surface (with almost no penetration). It is the most hazardous of the 3 bands and is referred to as the *disinfecting ray*. UV in this range must be purposefully produced.

For UV radiation to be effective in disinfection, the optimum wavelength is in the range 240 - 260 nm (in the UVC range). It is most effective when surfaces are thoroughly cleaned prior to application.

There are several considerations (Pros/Cons) when making a decision on the use of this process in a hyperbaric facility.

Pros:

- The CDC accepts this form of disinfection with certain limitations. (Rutala, 2008)
- UVC radiation is effective in destroying both surface and airborne pathogens (often referred to as 4D disinfection).
- Porous surfaces may be disinfected where there is direct line of sight to the UV source.
- There is no residue or odor after disinfection.

Cons:

- The EPA does not endorse processes, only chemicals.
- UV disinfection is less effective for fungal and bacterial spores.
- Disinfection requires a direct line of site. UVC radiation is not effectively reflected and does not work in shadows or otherwise concealed surfaces.
- UVC light does not penetrate easily (on a microscopic level in terms of thickness). Under any surface debris, pathogens are not readily accessible, and only the outer layers of any debris containing pathogens will be affected.
- Effectiveness is inversely proportional to distance from the source, making it difficult to achieve an effective dosage within a hyperbaric facility being multidimensional in terms of configuration. Closer surfaces may require potentially harmful over-dosing to reach surfaces further away.
- UVB and UVC radiation (wavelength shorter than 320 nm) is harmful to acrylic materials (windows). Acrylic windows must be protected with black-out screens (100% of light transmission blocked).
- Certain elastomeric and rubber-based materials will degrade with long-term exposure. Information concerning vulnerable materials is often hard to obtain.

Some studies using UV disinfection have been performed in hyperbaric facilities, but the author is of the opinion that this is not a suitable disinfection process. (Warren, 2020) (Browne, 2020) This is primarily due to the risk of damage to materials, exacerbated by the lack of line of site of many susceptible (and concealed) areas of the chamber. Patient contact surfaces such as beds, seats, chamber walls and floors can be disinfected, but as mechanical cleaning is required, using a suitable disinfecting chemical thereafter will achieve the same result.

Ozone (O_3)

O_3 is usually used in water treatment facilities, but advertised for other, surface disinfection applications. Effective disinfection requires a specific, predetermined exposure time, significant concentration, and it requires complete containment during use because O_3 is toxic.

The are a few considerations (Pros/Cons) when making a decision on the use of ozone and its application process in a hyperbaric facility.

Pros:

- O_3 would be effective for porous materials.

Cons:

- O_3 is not FDA approved.
- O_3 is not EPA endorsed for surface disinfection.

- The need for containment of O_3 effectively limits its use to items small enough to be placed in a suitable, securely sealed disinfection container.
- Residual amounts of O_3 may result in respiratory issues for vulnerable patients.
- O_3 has an aging effect on acrylic, polyethylene, neoprene and nitrile, leading to drying, degradation and embrittlement.

While O_3 is routinely used in some home respiratory equipment, the author does not deem it suitable for use in hyperbaric facilities. (Blanco, 2021)

Misting (including bio-fogging and electrostatic) Disinfectant Application

Misting is more about the application process than the disinfectant product. Advances in misting application control offer significant benefits over approved disinfectant products, although not endorsed by EPA (because this is a process rather than a chemical). (Cadnum, 2020) While there is no reason to consider this process any less effective, it should perhaps be considered as a sanitizing process (using an appropriately registered disinfectant).

The same process of selecting a disinfectant applies to misting, with all 14 criteria being applicable. Contact time for misting is the same as for soaking or wiping. Droplet size is used to determine the process terms used:

- Misting: 10 - 100 microns (µm)
- Fogging: 1 - 10 µm
- Electrostatic misting or fogging: 1 - 10 µm

The are a few considerations (Pros/Cons) when making a decision on the use of this process in a hyperbaric facility.

Pros:

- Smaller droplets can access smaller, partially enclosed or porous surfaces.
- Electrostatic misting and fogging particles are not gravity bound, and droplets should adhere to all charged surfaces equally, including those in enclosed or inverted locations.
- If the disinfectant chemical is benign to acrylic, the misting and fogging processes are not inherently harmful.
- These application processes are also effective for destroying residual airborne pathogens.

Cons:

- The EPA only permits soaking, spraying and wiping for the application of disinfecting chemical products.
- Misting and fogging droplets settle through gravity, making effective contact with some surfaces unlikely.
- Patients with compromised respiratory systems may be susceptible to irritation.
- If the disinfectant chemical is harmful to acrylic, acrylic surfaces must be covered with a solid material (not woven) and completely sealed off.
- Penetration into enclosed and porous surfaces make effective removal (e.g., flushing, removal, drying) difficult, given the configuration inside most hyperbaric chambers.

The author is of the opinion that electrostatic fogging is more suitable for hyperbaric chambers than misting or fogging, assuming the concern about effective removal can be addressed.

IMPLEMENTATION

Effective disinfection not only requires suitable products and/or processes, but it also relies on proper instruction, monitoring, and consistency. Hyperbaric facilities have many unique features, constraints and challenges when it comes to dealing with pathogens, potentially including the less appealing aspects of accessing bilges. Where a bilge is fitted, one is most likely to find a wide assortment of bacteria from human shedding and waste, together with pathogens brought into the chamber from outside.

The following stepwise approach to implement an effective plan may help in achieving appropriate and effective disinfection at a facility.

1. Compile a procedure encompassing the following:
    a. The types of materials and surfaces to be disinfected
    b. Access to surfaces, which may include moving items to ensure effective reach
    c. The degree of infection control required: sterilization, disinfection, sanitizing, cleaning, or an appropriate combination of these. In some cases, regular cleaning may be done more frequently than disinfection
    d. The expected pathogens
    e. The most suitable cleaning and disinfectant products. Perform a detailed evaluation to determine the most suitable disinfectant and/or process that is readily and consistently available
    f. The application process to be followed based on the above two criteria, including mechanical cleaning, soaking, spraying, wiping or fogging/misting
    g. The frequency of disinfection
        i. some areas may require more frequent cleaning, such as those in direct contact with occupants (typically after each treatment or daily)
        ii. immediate disinfection may be required where a known or suspected contamination has occurred
        iii. areas generally inaccessible to occupants (bilges, covered and concealed spaces) may need less frequent disinfection (typically monthly)
    h. Any external healthcare or other facility requirements, including restrictions on products, and disinfection validation requirements
2. Test the procedure for efficacy, engaging the facility infection control department, or an external service or laboratory.
3. Determine the staff health and safety requirements, including the required PPE. Evaluate any long-term exposure risks.
4. Compile training instructions including criteria for qualification of staff.
5. Thoroughly train staff and evaluate their ability to conduct proper disinfection.
6. Monitor for consistency, compliance and effectiveness.
7. Review and maintain records of all disinfections conducted, including details such as the disinfection product and/or process used, areas reached, person performing the procedure, date and sign-off.

FINAL WORDS

Based on research, regulations, experiences, current practices, product registrations and CDC guidelines, existing disinfection products and methods appear to be effective in ensuring and maintaining effective infection control for known pathogens withing a hyperbaric facility. The challenge is to also ensure safety of the facility, staff, and patients.

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CONTINUING EDUCATION CREDIT

This article has been reviewed and is acceptable for 1.0 Category A credit hour by the National Board of Diving and Hyperbaric Medical Technology.

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END NOTES

[1] The term 'pathogen' is used to describe microorganisms with known harmful effects on humans and animals. These microorganisms include bacteria, viruses, fungi, spores, and organisms that cause pathogens (e.g., parasites, protozoa).

[2] The US Environmental Protection Agency (EPA) does not consider a sanitizer a suitable means of inactivating controlling viruses, although many products will achieve this.

[3] Chemicals used to sterilize, disinfect or sanitize are referred to as 'pesticides'. This term is used as a collective name for bactericides, viricides, biocides, fungicides, germicides, and sporicides.

[4] NIOSH: National Institute for Occupational Safety and Health, or equivalent national organization, usually regulated by occupational safety and health requirements (OSH) – a requirement under the International Labour Organization (ILO).

[5] Personal Protection Equipment such as gloves, respiratory protection, and eye protection.

[6] NFPA 99, chapter 14 limits the presence of flammable vapors in oxygen enriched environments.