Low Temperature H$_2$O$_2$ Plasma Sterilizers

By Can Ahiska
Sterilization and Disinfection

Terminology

- **Sterilization**: A physical or chemical process that completely destroys or removes all microbial life, including spores.

- **Disinfection**: It is killing or removing of harmful microorganisms so they no longer cause diseases.

- **Disinfectant**: Products used to kill microorganisms on inanimate objects or surfaces. Disinfectants are not necessarily sporicidal, but may be sporostatic, inhibiting germination or outgrowth.

- **Antiseptic**: A product that destroys or inhibits the growth of microorganisms in or on living tissue.

- **Aseptic**: Characterized by the absence of pathogenic microbes.
Sterilization and Disinfection

Order of Resistance to Biocides

Varying resistance to chemical biocides of different types of organisms

<table>
<thead>
<tr>
<th>MOST RESISTANT</th>
<th>LEAST RESISTANT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacterial Spores</strong>&lt;br&gt;(e.g. Clostridium difficile)</td>
<td><strong>Vegetative bacteria</strong>&lt;br&gt;(e.g. Staphylococcus, Pseudomonas)</td>
</tr>
<tr>
<td><strong>Mycobacterial</strong>&lt;br&gt;(e.g. M. Tuberculosis)</td>
<td></td>
</tr>
<tr>
<td><strong>Nonlipid or small viruses</strong>&lt;br&gt;(e.g. Poliovirus)</td>
<td></td>
</tr>
<tr>
<td><strong>Fungi</strong>&lt;br&gt;(e.g. Candida)</td>
<td></td>
</tr>
<tr>
<td><strong>Lipid or medium sized viruses</strong>&lt;br&gt;(e.g. HIV)</td>
<td></td>
</tr>
</tbody>
</table>

Sterilization

- High level disinfection
- Intermediate level disinfection
- Low level disinfection
Sterilization and Disinfection

1968 – E. Spaulding Classification System

Earle H. Spaulding Classification System

Rational approach to disinfection and sterilization of patient-care items and equipment according to degree of risk of infection:

Three Categories:

1. Critical
2. Semi-Critical
3. Non-Critical
Critical Items:
- Objects that enter *sterile tissue* (breaks mucus membrane) or the *vascular system*
- High risk for infection if contaminated with microorganism.
- **Critical items must be sterile** because microbial contamination could transmit disease.

Critical Items Include:
- Surgical instruments
- Cardiac and Urinary Catheters
- Implants
- Biopsy Forceps
- Ultrasound probes used in sterile body cavities
- etc…
Sterilization

Methods of Sterilization
Sterilization Technologies

Steam Sterilizers

- The oldest and most cost-effective method for sterilization of items that are not heat/moisture-sensitive
- Destruction of microorganisms is dependent on temperature, pressure and time of exposure
- Steam must contact all surfaces of the item to be sterilized
- The outer jacket surrounding the sterilizer chamber to avoid excessive condensation in chamber.
Steam Sterilizers

**Advantages vs Disadvantages**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readily available</td>
<td>Unsuitable for an increasing number of heat and moisture sensitive devices (between 110°C-135°C)</td>
</tr>
<tr>
<td>Short cycle time</td>
<td>Efficacy dependent upon attention to detail</td>
</tr>
<tr>
<td>Nontoxic</td>
<td>Air retention and/or condensate pooling</td>
</tr>
<tr>
<td>Environmentally safe</td>
<td>Some instruments tend to loose sharpness after repeated exposure to steam</td>
</tr>
<tr>
<td>Economical</td>
<td>Water quality may promote stains or corrosion on instruments</td>
</tr>
<tr>
<td>Use with heat and moisture stable devices</td>
<td>Without good drying the packages are damp when removed from the sterilizer.</td>
</tr>
</tbody>
</table>

- Very powerful advantages making steam a cost / efficacy-effective sterilizer of choice
- However, some very real limitations due to its high-temperature and moisture dependency
Sterilization Technologies

Ethylene Oxide

- Introduced on 1940-50’s
- Low temperature sterilization
- Ethylene oxide sterilization is a chemical process consisting of four primary variables: gas concentration, humidity, temperature and time
- Ethylene oxide is an alkylating agent that disrupts the DNA of microorganisms, which prevents them from reproducing.
- Highly Penetrative
- Flammable and very Hazardous
## Ethylene Oxide Sterilizers

### Advantages vs Disadvantages

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective sterilization for heat and moisture sensitive Items</td>
<td>Specific process of Microbiological destruction not studied</td>
</tr>
<tr>
<td>Highly Penetrating Gas</td>
<td>Lengthy cycle time and aeration</td>
</tr>
<tr>
<td></td>
<td>Instruments must be completely dry</td>
</tr>
<tr>
<td></td>
<td>Flammable if not mixed with flame</td>
</tr>
<tr>
<td></td>
<td>Toxic fumes</td>
</tr>
<tr>
<td></td>
<td>Category 1 carcinogen</td>
</tr>
<tr>
<td></td>
<td>Mutagenic</td>
</tr>
<tr>
<td></td>
<td>High Installation and Hidden-Costs</td>
</tr>
</tbody>
</table>

- EtO gas characteristics make it a very effective sterilization agent, but also difficult to handle in hospital environment.
- EtO remains an effective sterilization method for industrial scale applications due to low-temp, and scalability.
Sterilization Technologies

Formaldehyde Sterilizers

- Introduced on 1940-50’s
- Higher temperature than EtO
- Formaldehyde gas is produced by liquid formaldehyde that is passed through a heated evaporator.
- Highly Penetrative
- Toxic and Hazardous
## Formaldehyde Sterilizers

### Advantages vs Disadvantages

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can sterilize heat and moisture sensitive items in approximately 3 hours</td>
<td>Formaldehyde exposure as regulated by OSHA is 0.75 ppm over 8 hour period</td>
</tr>
<tr>
<td>In newer system, FO is supplied in bags or bottles</td>
<td>Irritating to mucous membranes, carcinogenic</td>
</tr>
<tr>
<td></td>
<td>Higher temperature than EtO</td>
</tr>
<tr>
<td></td>
<td>Formaldehyde residue can remain on the sterilized goods if the rinsing phase is not 100% efficient. This can be harmful for the patients.</td>
</tr>
<tr>
<td></td>
<td>Adequate ventilation and alarm system needed for older models</td>
</tr>
<tr>
<td></td>
<td>A relative humidity of ~ 75% is required in order to be effective as the gas has to dissolve in a film of moisture surrounding the bacteria</td>
</tr>
<tr>
<td></td>
<td>Formaldehyde has not been FDA cleared for use in healthcare facilities and only recognized in some countries</td>
</tr>
<tr>
<td></td>
<td>High Installation and Hidden-Costs</td>
</tr>
</tbody>
</table>

- FO gas characteristics make it a very effective sterilization agent, but also presents significant residuals hazards.
H2O2 Plasma Sterilization

Basic Principles of Plasma Based Sterilizers

- Living microorganisms are hygroscopic (attracted to water)
- Sterilant and water are polar organic
- Preferentially they both condense on nucleation sites formed by the lying bacteria.
- They compete therefore high water vapor presence reduces sterilization efficacy.
- Viruses sizes are also efficient nucleation sites.
- A great quantity of highly concentrated vapours arrives and condense on the surface of bacteria colonies living in the materials.
- During the sterilization process the atmosphere constituted almost entirely by the vapour sterilizing in the chamber.
Why do we need a plasma?

Main Market Drivers for H2O2 Sterilization Devices

**SHIFT FROM ETO**
- Heavy regulations on EtO has been a good driver for the H2O2 sterilizer market for a time. In the U.S and EU countries there has been a huge reduction on EtO installations after heavy regulations (reached almost 0). In some other regions (ME, Asia and Africa), although there are still considerably amount of EtO installations, new sales rates are declining very fast and replaced with H2O2 sterilizers.

**MORE OPERATIONS**
- The number of over 60s will increase from 605 million in 2000 to over 2 billion by 2050
- This translates into high surgical procedures growth of over 10% p.a. in DMs

**MINIMAL INVASIVES**
- Endoscope market growing at ~8% per year in DMs
- MIS growing at 10% p.a.; $55bn market, Asian MIS market is growing at 15% plus p.a.
- Development of more advanced instruments, requiring delicate low temperature processing
- MIS means high turnout/turnover surgeries
- Approx. 9 million procedures applied at 2013 in US.

**EMERGING MARKETS**
- Surgical procedures growth in EMs two to fives times higher than in DMs, eg. over 25% for trauma procedures
- MIS increasing rapidly, worldwide
H2O2 Plasma Sterilization
Paradigm Shift in Low Temperature Sterilization

**ETHYLENE OXIDE (EtO)**
- ✔ Effective
- ✗ Costly installation & operation
- ✗ Hazardous on humans/environment (carcinogenic) ➔ Heavily Regulated
- ✗ Very Long Process duration

**FORMALDEHYDE**
- ✔ Effective
- ✔ Relatively economic in comparison to EtO
- ✗ Hazardous on humans/environment (carcinogenic) ➔ Heavily Regulated
- ✗ Long Process duration

**HYDROGEN PEROXIDE PLASMA**
- ✔ Effective
- ✔ Economical
- ✔ No toxic residue
- ✔ Short Process duration
Why do we need a plasma?

**Basic Features of H2O2 Sterilization Devices**

**CONCENTRATED STERILANT PROVIDE STHE HIGHEST STERILISATION EFFICACY** – Water vapor molecules in a sterilization chamber compete with the Sterilant molecules; therefore concentration of Sterilant increases the sterilization efficacy.

**BROAD MATERIAL COMPATIBILITY VIA DUAL MODE CONCENTRATOR INJECTOR** – With dual mode technology offers both variable concentration and none concentration cycles. Programs employs concentrated Hydrogen peroxide for optimized process duration.

**NO TOXIC RESIDUAL** - In-chamber plasma ensures Sterilant residue removal from medical instrument surfaces. The in–chamber plasma and in-line efficient catalytic converter ensure that there is no residual H2O2 leakage from the sterilizer.

**ISO 14937 COMPLIANT TEST VALIDATION FROM ACCREDITED LAB** - Sterilization processes must be validated to $10^{-6}$ SAL (Sterility Assurance Level) by an ISO/EN 17025 accredited European laboratory.

**QUALITY** - Products should be manufactured under continuous quality control to appropriate medical and product quality standards with EN ISO 13485, EN ISO 9001, and full CE (EMC EN 60601-1-2, EMC EN 60601-1-2, and LVD IEC 61010-1) certification.

**RAPID THROUGHPUT** – With shortest cycle times for the low temperature sterilization, plasma sterilizers is one of the best and fastest methods to process delicate medical instruments in your hospital.
The Ideal Sterilizer!

- Safe for people and the environment
- Short cycle
- Easy to install
- Easy Monitoring

Low temperature
Material compatibility
Cost effective
Low Temperature H₂O₂ Sterilizers

How does a plasma sterilizer works?

Vacuum Conditioning

The Sterilization process requires deep vacuum for the hydrogen peroxide to remain in vapor phase at low temperatures.

Plasma Conditioning

The Chamber is pre-conditioned with plasma in order to:
(i) remove moisture
(ii) enable homogenous heat distribution.

1st Hydrogen Peroxide Injection

The previously conditioned H₂O₂ Sterilant is injected into the sterilization chamber as a vapor.

1st Diffusion

After injection into the chamber, the H₂O₂ is maintained as a vapor in order to enable homogenous and effective diffusion inside the lumens and cavities of the surgical instruments.
Low Temperature $\text{H}_2\text{O}_2$ Sterilizers

How does a plasma sterilizer works?

Vacuum Operation

The Chamber is evacuated to vacuum in preparation for the 2nd Injection Phase.

2nd Hydrogen Peroxide Injection

Once again: The previously conditioned H2O2 Sterilant is injected into the sterilization chamber as a vapor.

2nd Diffusion

Once again: After injection into the chamber, the H2O2 is maintained as a vapor in order to enable homogenous and effective diffusion inside the lumens and cavities of the surgical instruments.

Vacuum Operation

The Chamber is evacuated to vacuum in preparation for the Plasma Abatement stage.
Low Temperature H₂O₂ Sterilizers

How does a plasma sterilizer works?

Plasma Abatement
The plasma at the end of the cycle, ensures that all H₂O₂ is decomposed (to water vapor and oxygen) and contributes to the sterilization via the UV and free radicals generated.

Optional Areation
The Chamber is vented with purified dry air to provide further cleansing.
Plasma
Fourth State of Matter

Solid
H₂O (s)

Liquid
H₂O (l)

Gaseous
H₂O (g)

Plasma
H₂O \{H, H₂, H⁺, e⁻, H₂⁻, O, O₂, O₃, O⁻, O₂⁻\}

Energy/Temperature
Molecule
Molecule (excited)
Ions
Molecular fragment (high energy)
Free electron
Low Temperature H$_2$O$_2$ Sterilizers

**Why In-Chamber Plasma?**

3 key uses of plasma in H$_2$O$_2$ sterilizers:
- Min. residual sterilant left on medical instrument surfaces.
- Homogeneous Heating and Humidity reduction.
- Increases sterilization efficacy.
- Min. H$_2$O$_2$ exposure to environment

- **Pre-cycle conditioning**: prior to injection of H$_2$O$_2$ Sterilant, plasma application generates controllable homogenous heating up to 55°C at low pressure vacuum for the preconditioning of the instruments and moisture removal.

- **Post-cycle decomposition**: during the cleansing phase of the sterilization cycle, plasma application is used to decompose the H$_2$O$_2$ Sterilant (to water vapor and oxygen).
Low Temperature H₂O₂ Sterilizers

**Concentration Technology**

**In-situ H₂O₂ Concentration substantially improves sterilization efficacy:**
- The presence of water vapor adversely affects the sterilization efficacy of the H₂O₂ sterilization process. With reduction of water vapor in the sterilization chamber, this technology ensures repeatable lumen cycle performance.
- In-situ device concentration technology to:
  - Increase the sterilization efficacy
  - Reduce cycle time

**Controllable Dual Mode Concentrator:**
- A H₂O₂ sterilizer must offer dual mode injector technology, providing users with more flexibility of programs to better protect your medical instruments and provide increased sterilization efficiency at the same time.
Material Compatibility

Physical factors that affect Material Compatibility

1. **H₂O₂ Exposure**
   
   **Duration**: With identical diffusion (contact) durations For all cycles, must have identical H₂O₂ exposure!

2. **Temperature**
   
   Sterilization process within same in-chamber temperature range

3. **Residuals**
   - Aeration (air-wash)
   - Plasma

4. **Plasma (Power & Duration)**
   
   Plasma Technology power must be optimized otherwise lead to etching.

5. **Diffusion Pressure**
   
   Same pressure band as most brands.
## Sterilization Technologies

### “Ideal” Characteristics Summary

<table>
<thead>
<tr>
<th></th>
<th>Steam</th>
<th>EtO</th>
<th>FO</th>
<th>H2O2 Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High efficacy</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Water quality dependent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rapid activity</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Long aeration required</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Strong penetrability</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Material compatibility</strong></td>
<td>✓ / ✓ Not for sensitive instruments</td>
<td>✓</td>
<td>✓</td>
<td>✓ Not for Cellulosics</td>
</tr>
<tr>
<td><strong>Nontoxic</strong></td>
<td>✓</td>
<td>Hazardous!</td>
<td>✓ / ✓ Hazardous!</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Adaptability</strong></td>
<td>✓ / ✓ Bench top mobile</td>
<td>X</td>
<td>Heavy installation requirements</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Monitoring capability</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Cost-effectiveness</strong></td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Hidden operating costs</td>
<td></td>
<td></td>
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</tbody>
</table>

**Low Temperature Sterilization**
Sterility Assurance

Validation & Routine Process Monitoring

**Biological Growth Test:**
- \( \text{H}_2\text{O}_2 \) Geobacillus stearothermophilus spores (106 population)
- Incubation time/conditions: 24 hours at 55°C

**Chemical Indicators:**
- Routine monitoring hydrogen peroxide chemical indicator
- Per-Tyvek Hydrogen peroxide chemical indicator

**Routine Monitoring Kit**
For routine process monitoring to ensure that the sterilizers are continuously operating at peak performance.
- Compliant with ISO 14937 routine monitoring guidelines
- 2x1200mm PCD-BI Test Challenge Device with 1x Box ST800
- (Supplementary) 2x1200mm CI Helix Challenge Test with 1x Box ST810
Sterility Assurance

Validation & Routine Process Monitoring

Full conformance with EN ISO14937 Article 8.3 (a) and (b) is only possible with an appropriate PCD-BI.

- Heat & Chemical Resistive Viton O-ring
- Shrink fit on lumen-to-receptacle to prevent leak and to improve durability to leakage from repeated twisting.

- Self-Contained Biological Indicator (SCBI)
- No “Booster Effect” due to no extra volume. SCBI fits tightly into receptacle.
- Wall thickness does not allow H2O2 penetration.

In an environment with no standard for VH2O2 sterilization, it is our responsibility to devise a truly challenging PCD.

- Teflon Lumen
- Single-end blocked
- Lumen length and inner radius to simulate our “sensible” lumen claims (i.e. comparable to industry leaders).
  2mm (⌀) * 1200mm (L)
Preparing

Preparing of Load
Preparing

General Guidelines

• **Always** follow the **instrument manufacturer’s instructions**/recommendations during Preparation, Packaging and Placing.

• Full **PPE must be worn** for handling and cleaning contaminated equipment/devices.

• Reusable medical instruments must be **thoroughly cleaned** before disinfection or sterilization, and thoroughly **dried before sterilization**.

• **Tools** used to assist in cleaning, such as brushes, must be cleaned and **disinfected after use**.

• **Equipment** used during cleaning process should be regularly **maintained, cleaned and calibrated** as per manufacture's instructions.

• All **consumables** (e.g. ultrasonic solutions) should be **replaced** as per manufacturer’s instructions.
Preparing

Preparing Instruments for Sterilization

The process for cleaning should include written protocols for disassembly, sorting and soaking, physical removal of organic material, rinsing, drying, physical inspection and wrapping.

• **Disassembly** - Instruments should be disassembled prior to cleaning as per the manufacturer’s recommendations/instructions.

• **Sorting** - Sort equipment/devices into groups of like products requiring the same processes.

• **Soaking** - Soak equipment/device in an approved soaking solution to prevent drying of soil, making cleaning easier.

• **Physical removal of organic material** - Gross soil may be removed using tools such as brushes and cloths.
  - **Manual** - If manual cleaning is performed, physical removal of soil must occur under the water level to minimize splashing.
  - **Washer-disinfectors** are strongly recommended for medical equipment/devices that can withstand mechanical cleaning, to achieve the required exposure for cleaning and to reduce potential risk to personnel.
  - **Ultrasonic washers** are strongly recommended for any semi-critical or critical medical equipment/device that has joints, crevices, lumens or other areas that are difficult to clean.
Preparing Instruments for Sterilization

The process for cleaning should include written protocols for disassembly, sorting and soaking, physical removal of organic material, rinsing, drying, physical inspection and wrapping.

- **Rinsing** – Thorough rinsing following cleaning is necessary as residual detergent. Perform the final rinse for instruments containing lumens.

- **Drying** – Prevents dilution of chemical disinfectants which may render them ineffective and prevents microbial growth. Equipment/devices may be air-dried (recommended for instruments with lumens) or dried by hand with a clean, lint-free towel.

- Low Temperature H2O2 Plasma Sterilizers rely on moisture-free and deep-vacuum pressure conditions for an effective sterilization process, therefore effective drying is essential to prevent any unnecessary cycle aborts.

- **Inspection** - Visually inspect all instruments to ensure cleanliness and integrity (e.g. cracks, defects, adhesive failures).
  - Repeat the cleaning if necessary!

Do not reassemble equipment/device prior to disinfection/sterilization.
Packaging

Preparing of Load
Packaging

Chemical Indicators

- One $\text{H}_2\text{O}_2$ Chemical Indicator *recommended to be placed in every sterilization package*

**Chemical indicators**: use sensitive chemicals to assess physical conditions such as temperature during the sterilization process. Chemical indicators such as heat sensitive tape change color rapidly when a given parameter is reached. A chemical indicator should be placed in every sterilization package to ensure the sterilization agent has penetrated the packaging material and actually reached the instruments inside.
Packaging

Biological Indicators

- One Tyvek sealed Biological Indicator *recommended* be placed with the load in *at least one* sterilization cycle *every day*.
- Recommended use, one Tyvek sealed Biological Indicator per cycle.

**Biological indicators (BIs):** are the most accepted means of monitoring the sterilization process because they directly determine whether the resistant microorganisms (e.g., Geobacillus or Bacillus species) are present post-cycle, rather than determining whether the physical and chemical conditions necessary for sterilization are met. Because spores used in BIs are more resistant and present in greater numbers than are the common microbial contaminants found on patient care equipment, an inactivated BI indicates that other potential pathogens in the load have also been killed.
Top Loading:
It is recommended not to place packaged instruments above each other (i.e. a second layer above the first layer of instruments in the tray). Top loading may limit the free diffusion of H2O2 gas throughout the load.
Thank you!