

Sterilization of Plastics

Introduction

The rising use of plastics in medical devices means that the capability of being sterilized is rapidly becoming a key selection criterion for any plastic to be used in a medical device.

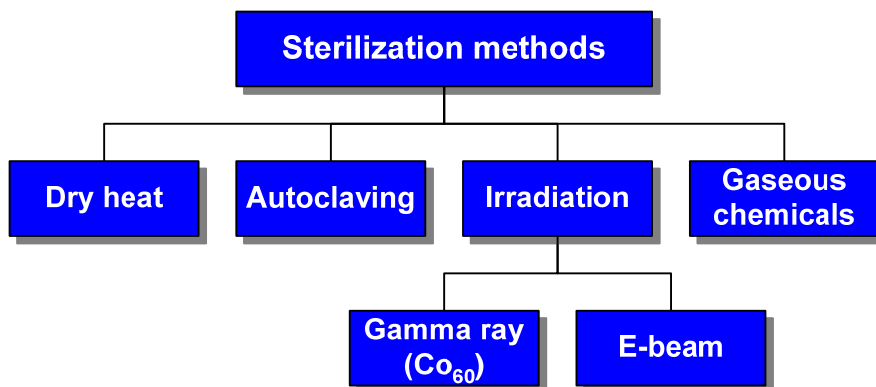
The objective of sterilization is to prevent the introduction into the body of pathogenic organisms not normally present. Sterilization can be defined as 'the removal or destruction of all living organisms, including resistant forms such as bacterial or fungal spores'. Bacterial spores are most resistant to destruction, and if the sterilization is effective in eliminating bacterial spores then it can generally be assumed that all other pathogenic and non-pathogenic organisms have been destroyed.

Disinfection is a lower grade of sterilization and involves only the destruction of pathogenic organisms in the vegetative (or non-sporing) state; it does not involve the destruction of spores.

Sterilization is the only acceptable standard for surgical purposes although disinfection may well be suitable for other purposes.

Sterilization Methods

Sterilization can be achieved through a variety of methods and these will be considered individually with particular emphasis on the applicability of the method to the sterilization of plastics devices. No matter which sterilization method is used, the objective is to reduce the bioburden (the number of microorganisms present) to a safe level. [Production in a 'clean room' (of any standard) does not make a device sterile; it simply reduces the initial bioburden and concentration of foreign particles to make sterilization more effective.]



The main sterilization methods for medical devices



Dry Heat

Dry heat is not generally regarded as being suitable for plastics due to the low thermal transmission properties of plastics and the difficulty of insuring that all parts of the product have been exposed to the required temperature for an adequate time. Most plastics will degrade during prolonged dry heat sterilization.

Autoclaving

Autoclaving uses saturated steam to allow lower temperatures and shorter times than in the dry heat process. Steam will penetrate well into a product, as water vapor is lost due to condensation. Ideally proper autoclaving will allow steam to reach all surfaces and for items to reach the required temperature for sterilization. The temperatures and times used for autoclaving vary depending on the particular cycle chosen (lower temperatures must be held for longer times), but it is common for the temperature to be around 121°C (250°F) @ 0.5 bar¹ for average cycle times. Conditions that prevent the steam from reaching the surface, e.g. poor cleaning, improper packaging or over packing of the autoclave can seriously reduce the effectiveness of autoclaving as a sterilization method.

Some materials will lose structural integrity at the temperatures used for autoclaving. Devices made from such materials need to be supported to prevent slumping and distortion of the product. Even products where the softening temperature is higher than the autoclaving temperature can suffer from the release of molded-in stresses and subsequent distortion. Where autoclaving is to be used, the effect of multiple sterilization cycles needs to be considered to prevent cumulative effects of the treatment on the plastic. If the devices are to be packaged before autoclaving then the packaging material and packaging method needs to be carefully chosen. The suitability of a package for autoclaving will depend on the material, the size of the package, the wall thickness of the package and the contents.

As a general rule autoclaving is used significantly in hospitals for the sterilization of repeated use articles. It is not the predominant method in the commercial sterilization of medical devices because of the difficulties involved with autoclaving packaged products.

Irradiation

Irradiation is commonly used for sterilization and can be generated by either gamma rays from a Cobalt (Co₆₀) source or an electron beam (E-beam). In both cases the cost of capital equipment is great, but high throughputs will improve the return on investment.

¹ Bar: Unit of measurement for pressure. 1 bar = 14.50psi



Dosage for either process is measured in Megarad (Mrad) and as a general rule a radiation dose of around 2.5 Mrad will sterilize clean articles in air. The required dosage will be approximately twice as high in anaerobic conditions. It is important to recognize that this is the minimum dosage and equipment will be set to deliver this as a *minimum* dosage – the actual delivered dosage is often much higher.

Both gamma and E-beam sterilization use radiation and the effect on plastic materials is the same for both. Many plastics are resistant to radiation at doses of up to around 2.5 Mrad. The actual doses used will be higher than this to achieve sterilization, however complete sterilization and radiation damage of some magnitude will inevitably occur. The effect of radiation is cumulative and for items that must be repeatedly sterilized the total dosage can rise rapidly. For these items records need to be kept to insure that safe limits are not exceeded. Irradiation is very effective for fully packaged and sealed single-use items (most plastic films are effectively transparent to radiation) where only one radiation dose is required.

Plastic devices subjected to irradiation sterilization will inevitably be affected by the radiation and the environment used during sterilization, and will experience changes in the polymer structure such as chain scission and cross-linking. These processes will lead to changes in the tensile strength, elongation at break and impact strength. The exact changes seen will depend both on the basic polymer and any additives used. The changes in mechanical properties may not be immediately apparent and there can be some time delay in their development. One visible side effect of irradiation sterilization is that many plastics will discolor or yellow as a result of the processing (although this may fade with time).

Irradiated devices are completely safe to handle and can be released and used immediately after sterilization.

Gamma Rays

Gamma rays are produced from a Co_{60} source and have a high penetrating power (up to 50 cm). This allows a high packing density in the sterilization chamber. This can also mean that products at the outer edges of the packing can be subjected to much higher radiation doses than those at the center of the pack. Materials to be gamma sterilized need a margin of error in their resistance to radiation to insure that there is no excessive degradation if items are at the outer edges.



E-beam

E-beam sterilization uses an E-beam generator (between 1 MeV² and 12 MeV) to produce a beam of high energy electrons that destroys organisms. The E-beam electrons have a much lower penetrating power, but higher dose rates than gamma rays and will only penetrate around 5 cm. This means that the packing density must be low to insure that the electrons reach the center of the pack. As with gamma rays, products at the edges of the pack are subjected to higher doses than products at the center to insure that full sterilization is achieved.

The higher dose rates and shorter times used for E-beam sterilization can slightly improve the dosage to produce substantial damage due to the reduced exposure to oxygen during the process.

Gaseous Chemicals (EtO)

Ethylene oxide is a powerful alkylating agent and is regarded by the EPA as a toxic and possibly carcinogenic gas (exposure to EtO is regulated by the EPA and OSHA). When mixed with air, EtO is not only flammable but can also be explosive.

The effectiveness of EtO sterilization depends on many variables such as time, gas concentration, temperature and relative humidity (necessary to moisten bacteria to insure effective destruction). This has made monitoring EtO sterilization difficult and time consuming in the past although the development of parametric release methods as a substitution for standard biological indicators is reducing the time taken for clearance and approval.

EtO sterilization requires evacuation of the sterilization chamber, the introduction of moisture, the introduction of the EtO gas (either in the pure state or as a 10 to 15% mixture with an inert gas), and keeping the internal pressure of the chamber lower than one atmosphere³ to prevent leakage of the EtO to the atmosphere. After the specified exposure time, the EtO is purged and the chamber is flooded with filtered sterile air to remove any residual EtO. This complex process and subsequent monitoring takes longer than radiation sterilization but recent technology advances have greatly reduced the cycle time for EtO sterilization.

The majority of plastics are unaffected by EtO sterilization treatment, but some can absorb EtO and these must be treated to eliminate any EtO before use.

² MeV: Mega electron volt. 1 MeV = 1.602×10^{-13} J. J stands for Joule, the standard unit for energy.

³ Atmosphere: Unit of measurement relating to pressure. 1 atmosphere = 14.69psi



Some plastics are relatively permeable to EtO and the process can then be used to sterilize fully packaged articles by using thin packaging films, such as PE, that allow the EtO gas to enter the package and sterilize the contents. The packaging film must also be permeable to water vapor and air to be effective.

Standards

AAMI and ISO have produced a range of standards for sterilization such as:

- ISO 11135 - Medical devices - Validation and routine control of ethylene oxide sterilization.
- ISO 11137 - Medical devices - Validation and routine control of radiation sterilization.
- ISO 11737 - Sterilization of medical devices - Microbiological methods.
 - Part 1: Estimation of population of microorganisms on products.
 - Part 2: Tests of sterility performed in the validation of a sterilization process.

The Response of Plastics

Design for Sterilization - Polymer Selection

One of the greatest difficulties with sterilization of medical devices is the range of plastics used in any given device or kit. A simple device or kit may contain up to 10 different plastics for a range of uses, e.g. housings, tubing, connectors, valves, and seals. The plastics used may be chosen for a variety of reasons such as transparency, mechanical strength, or inertness depending on the application. The difficulty is that every plastic behaves in a different manner to the various sterilization methods used. Manufacturers can easily find that the completed device cannot be effectively sterilized. If manufacturers make unwise material choices, (i.e. each material may preclude a specific sterilization method and if disassembly is not possible) then it may be impossible to adequately sterilize the completed device.

The possible sterilization methods therefore need to be considered as an integral and early part of the materials selection process for all medical devices using plastics. An additional complication in the materials selection process is the multiplicity of grades available, even for a nominally identical plastic material. For example, PVC is available in several different major materials families depending on the production method, (e.g. suspension PVC, emulsion PVC and mass polymerized PVC, and in tens of thousands of different grades which will vary according to plasticizers), fillers and other additives. Each of these grades will vary in their response to the main sterilization methods - simply giving the response of 'PVC' to a specific sterilization method is not a definitive answer.



The response must be specific for the selected grade in order to be absolutely confident of the actual service behavior.

It is often not possible to state if a given material can be sterilized by a specific method, especially in a short newsletter and often the best information simply gives guidance on the methods which cannot be used. The general performance of a range of plastics is given in the table below, however specific guidance for individual materials combinations and products is recommended.

Material	Autoclave	Radiation (Dosage to produce substantial damage)		EtO
		Gamma	E-beam	
Engineered Plastics				
PTFE	✓	× (< 1 Mrad)	× (< 1 Mrad)	✓
FEP	✓	10 - 20 Mrad	10 - 20 Mrad	✓
ECTFE / ETFE	✓	100 Mrad	100 Mrad	✓
PCTFE	✓	10 - 20 Mrad	10 - 20 Mrad	✓
PE-HD	×	100 Mrad	100 Mrad	✓
PE-LD	×	100 Mrad	100 Mrad	✓
PET / PBT	✓	100 Mrad	100 Mrad	✓
Commodity Plastics				
Acetal (POM)	✓	× (< 2.5 Mrad)	× (< 2.5 Mrad)	✓
PA	✓	× (< 2.5 Mrad)	× (< 2.5 Mrad)	✓
PC	✓	100 Mrad	100 Mrad	✓
PMMA	×	5 - 10 Mrad	5 - 10 Mrad	✓
PP - GP	✓	10 Mrad	10 Mrad	✓
PPS	✓	5000 Mrad	5000 Mrad	✓
PS	×	1000 Mrad	1000 Mrad	✓
PSU	✓	1000 Mrad	1000 Mrad	✓
PVC - plasticized	×	50 Mrad	50 Mrad	✓
PVC - unplasticized	✓	50 Mrad	50 Mrad	✓



The Fluorocarbons

The fluorocarbons have a mixed response to sterilization. The majority of the materials are highly suitable for all the major sterilization methods and can be sterilized by any of the common methods. The exception is PTFE, which is suitable for autoclaving and EtO treatment but has a low resistance to gamma and E-beam radiation sterilization. PTFE can suffer substantial radiation damage at exposures less than those required for adequate sterilization.

Summary

Plastics, particularly the fluoropolymers, are being used increasingly in medical devices (both single and multiple use). The sterilization capabilities are important to everyone, from the designer to the final patient. For medical devices, the preferred sterilization method (as well as the biocompatibility, as discussed in the last Whitepaper) can dictate the available materials. If poor materials selection processes are used then the materials chosen can dictate the sterilization process.

It is inevitable that more plastics will be used in medical devices in the future, and product designers, materials suppliers, and materials processors will need to know more about this complex subject in the future. Zeus provides a wide array of polymers that are both sterilizable by a variety of methods and biocompatible, making the medical device materials selection process easier for the designer.

How Zeus Can Help

With a technical inside and outside sales force backed up with engineering and polymer experts, Zeus is prepared to assist in material selection and can provide product samples for evaluation. A dedicated R&D department staffed with PHD Polymer chemists and backed with the support of a world-class analytical lab allows Zeus an unparalleled position in polymer development and customization.

Since 1966 Zeus has been built upon the core technology of precision extrusion of high temperature plastics. Today, with a broad portfolio of engineered resins and secondary operations, Zeus can provide turnkey solutions for development and high-volume supply requirements.

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