Bio-decontamination processes compared: hydrogen peroxide vapour and chlorine dioxide

Bio-decontamination technology in its most basic form originated with the earliest development of aseptic techniques. Pasteur's work in 1861 on spoilage of foodstuffs by microorganisms, and the subsequent development of pasteurisation, laid the foundations for the modern principles of aseptic technique and manufacture. Whether it is employed in hospitals to prevent patient infection, food processing to prolong shelf-life or pharmaceutical manufacturing to ensure product integrity, the ability to bio-decontaminate whole rooms, enclosures or pieces of equipment is a vital component in the maintenance of an aseptic environment.

When reviewing the best method of bio-decontamination to apply for any given application, it should be considered on its merit in a number of areas such as safety, efficacy, ease of use and compatibility. Due to those factors, using formaldehyde (one of the older bio-decontamination methods) is becoming increasingly rare as safer methods are sought. Copious data exists for a number of alternative methods of bio-decontamination; this paper reviews the available information and compares/contrasts two of the more widely implemented methods, hydrogen peroxide vapour (HPV) and chlorine dioxide (CD).

bioquell

Comparing hydrogen peroxide vapour and chlorine dioxide bio-decontamination processes

When seeking a room or enclosure bio-decontamination solution, hydrogen peroxide vapour (HPV) and chlorine dioxide (CD) are often short-listed. However, each method poses challenges that result in different outcomes. The following information helps to identify the strengths and weaknesses of both of these methods and compares them in an analytical manner. To examine the merits of each process further, independent peer-reviewed scientific data should be consulted.

Safety

The need to ensure employee safety in any biological decontamination method is clearly of paramount importance. When coupled with an increasingly litigious working environment, employers have to be clear about the risks to their employees around any method using a potentially toxic chemical.

CD is roughly ten times more toxic than HPV. The OSHA permissible exposure limit (PEL) for CD is 0.1ppm[a]; the 15 minute short term exposure limit (STEL) is 0.25ppm[b] and the NIOSH immediately damaging to life and health (IDLH) is 5ppm.[c]

By comparison, HPV has a PEL of 1ppm, a STEL of 2ppm and an IDLH of 75ppm. Regardless of the above figures, you need to consider **both products are toxic and care should be taken at all times when handling**, but these figures show that CD is a very dangerous chemical to manage.

The concentration of CD used for bio-decontamination of a room is typically 700ppm compared to HPV which is used at around 200ppm. There is also a difference between the two physical descriptions; HPV is used as a gaseous 'vapour' whereas CD is employed as a 'gas'. The most important thing to remember is that there is no major difference between a vapour and a gas. These are just terms to describe a phase of a substance, and there are many similarities between the two terms, which makes precise definitions practically impossible. The 'gas' state of CD and 'vapour' state of HPV result in good levels of distribution. However, the lower levels of toxicity exhibited by HPV, together with the lower concentrations within the target area and the 'lazier' (non-diffusive) nature of the vapour, alter the risk profile significantly. These effects were particularly observed during the SARS crisis in Singapore, where hospital decontaminations were performed in wards adjacent to occupied rooms.[1]

When broken down by light and water, CD forms toxic chlorine gas and highly corrosive hydrochloric acid. HPV simply decomposes to water vapour and oxygen.

Chlorine dioxide breakdown

$2ClO_2$ + sunlight = Cl_2 + $2O_2$

and

$ClO_2 + 2H_2O + 4e = Cl + 4OH$ $\quad E° = 0.76V$

Hydrogen peroxide breakdown

$2H_2O_2 = 2H_2O + O_2$

The HPV breakdown, whilst occurring naturally in the environment, is faster when using suitable catalysts. Leading manufacturers often employ these during the aeration phase of the HPV process.

Considering stability, the NIOSH website says the following about CD;

"Conditions contributing to instability: Chlorine dioxide is a very unstable material even at room temperatures and will explode on impact, when exposed to sparks or sunlight, or when heated rapidly to 100 degrees C (212 degrees F). Airborne concentrations greater than 10 percent may explode."

In addition, the website states;

"Incompatibilities: Contact with the following materials may cause fires and explosions: carbon monoxide, dust, fluoroamines, fluoride, hydrocarbons (e.g., butadiene, ethane, ethylene, methane, propane), hydrogen, mercury, non-metals (phosphorus, sulphur), phosphorus pentachloride-chlorine mixture, platinum, or potassium hydroxide. Chlorine dioxide reacts with water or steam to form toxic and corrosive fumes of hydrochloric acid."

The risk of explosion of 30-35% hydrogen peroxide solution is negligible and trials have demonstrated that HPV produced by the Bioquell vaporisation process does not explode in the presence of electrical sparks or electronic equipment.

Efficacy

Second only to safety must be the need to prove efficacy of the selected bio-decontamination method. This may be in the form of broad-spectrum efficacy utilised to reduce the general bioburden or the specific efficacy against a particular target organism. Before comparing the processes, it is vital to understand the methodology behind the efficacy studies being cited by the manufacturers. For example, was the chemical species used in the appropriate form (gas vs aqueous), as efficacy can differ based on state.

Following the 2001 contamination of the Hart Senate Building in Washington D.C. with anthrax spores, extensive testing was carried out in which various *Bacillus* spores (the most resistant microorganisms according to the Spaulding scale) were subjected to HPV and CD bio-decontamination cycles.[2]

[a] Permissible exposure limit – set by the Occupational Safety and Health Administration (OSHA) is the permissible exposure concentration calculated as an 8 hour time weighted average (TWA)
[b] Short term exposure limit (UK) – the permissible short term exposure concentration calculated as a 15 minute TWA
[c] Immediately damaging to life and health – set by the National Institute for Occupational Safety and Health (NIOSH) is defined as an atmospheric concentration of any toxic, corrosive or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere.

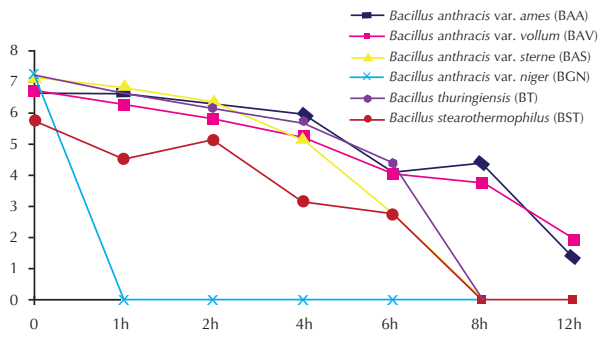

Figure 1. Chlorine dioxide bio-decontamination: Chart showing remaining colony forming units of *Bacillus* spores following a decontamination cycle of 70% RH and 620ppm

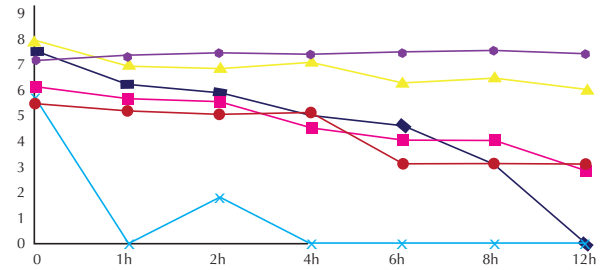

Figure 2. Chlorine dioxide: Chart showing remaining colony forming units (CFUs) after bio-decontamination cycle of 70% RH and 750ppm

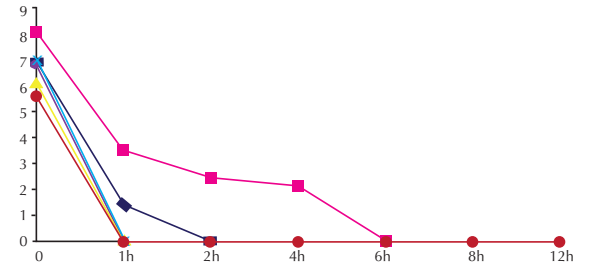

Figure 3. Hydrogen peroxide: Chart showing remaining colony forming units after bio-decontamination

These independent results demonstrated that HPV was more efficacious against the spores than either concentration of CD, although studies that are more recent suggest that with careful environmental control and pre-conditioning, CD can demonstrate comparable efficacy to HPV.

Ease of use

When describing the ease of use of a bio-decontamination method, it is useful to consider a number of factors such as pre-conditioning requirements, residues, outgassing, downtime and equipment compatibility.

Pre-conditioning requirements

CD requires very specific starting conditions in order to be efficacious. Typically, a starting relative humidity of at least 70% and a temperature of 70°F (21.1°C) must be achieved before the bio-decontamination process can be started.[3] It is also necessary to be extremely careful when isolating areas not to be gassed due to the pervasive nature of CD.

HPV cycles are carried out at a broad range of room temperatures and relative humidities, encompassing those normally found in standard laboratories and pharmaceutical manufacturing areas. HPV also requires only a basic sealing of the target areas, typically achieved using adhesive tape carrying special warning signs.

Residues

As mentioned earlier, when broken down by light and water, CD forms toxic chlorine gas and highly corrosive hydrochloric acid. Alternatively, sodium bisulphate can be used to neutralise CD. Unfortunately, this chemical leaves a powdery residue that requires post-decontamination cleaning, incurring additional time and labour costs.

Bio-decontamination using HPV leaves no process residues, as the HPV breaks down into water vapour and oxygen.

Outgassing

According to the US EPA, CD is absorbed into a wide range of materials and 'outgasses' for an extended period after a cycle has been run. This means that there can be ongoing issues over the continued presence of CD and the products it decomposes to.

In comparison, HPV is only absorbed into a limited number of material types. Though there is no quantitative data available, the US EPA describes HPV outgassing as 'rapid'. This means that outgassing is often dealt with during the aeration phase of the overall bio-decontamination cycle.

Downtime

Downtime significantly affects the ability of a business/organisation to maintain high performance and efficiency levels. Whilst the fumigation processing time can be faster with CD, the overall time it takes to prepare the room or building can make this treatment a protracted process.

Significant time and a high labour requirement are needed to achieve the specific starting conditions and remove the residues left by CD. In contrast, these requirements are not necessary for a HPV bio-decontamination process. The practical problems associated with CD downtime were evident during the Hart building decontamination process. The team experienced two 'lengthy' aborted cycles as the starting conditions could not be achieved.[2]

Compatibility

One of the most contentious areas of comparison between bio-decontamination processes is compatibility with exposed materials. When comparing studies into the effects, care must be taken to examine the method of exposure along with details about duration and repeatability. There must also be a clear explanation of the method of analysis that identifies any of the material changes that occur.

It is increasingly important that bio-decontamination technology suppliers provide material testing results. Requests for information about new or novel materials should be provided with a scientifically sound protocol. This should provide clear details on any potential compatibility issues.

CD is known to have significant material compatibility problems; most notable for the pharmaceutical industry are reports of stainless steel incompatibilities and concerns regarding electronic devices.[4]

The following example demonstrates the difference between the corrosive properties of the two systems in practical terms:

A presentation given to explain the use of CD in the Capitol Hill anthrax decontamination has 'reasonable materials compatibility' as one of its titles. Under the heading it explains what is meant by reasonable – 'computer non-functional after 5 treatments'. This means that it is not practical to decontaminate computer equipment with CD.

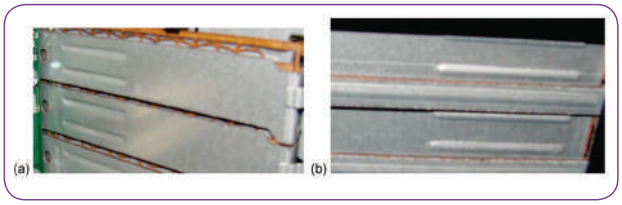

Figure 4. Internal (a) and external (b) corrosion of PCI slots in CD exposed computers (Photographs courtesy of EPA)[5]

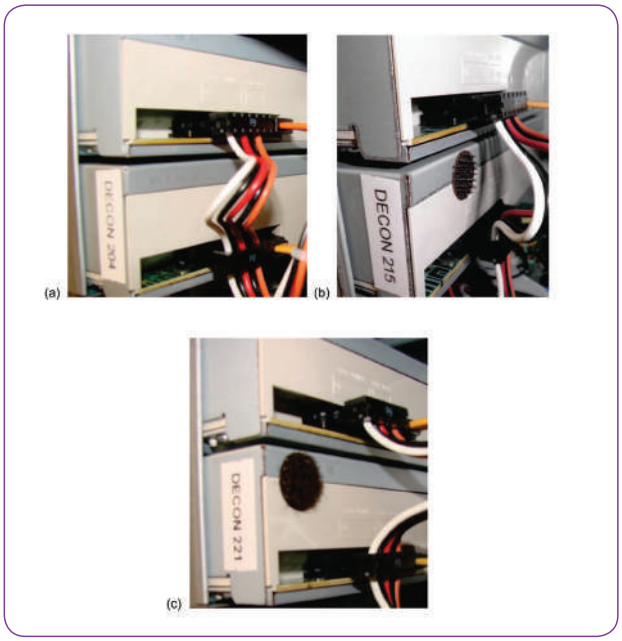

Figure 5. An unexposed compact disc-ROM drive casing (a), corrosion due to CD at a high RH (b) and corrosion due to CD at a lower RH (c) (Photographs courtesy of EPA)[5]

During HPV materials compatibility testing conducted by Bioquell, a computer was subjected to 860 cycles. There were no adverse effects.

Industry estimates of more than 1000 HPV installations world-wide suggest compatibility concerns with HPV are minimal from an end user perspective. Furthermore, extensive and ongoing testing programs aim to use good scientific methods to provide data for clients with any materials of concern.

Summary

When considering CD and HPV as alternative methods of bio-decontamination, both methods have various merits for achieving good results. However varying levels of importance will be placed on some of the factors given in this document in different situations, so careful appraisal of all of the factors that are important should be made.

References

1 U.S. EPA. Workshop on Decontamination, Cleanup, and Associated Issues for Sites Contaminated With Chemical, Biological, or Radiological Agents. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/083, 2005.

2 U.S. EPA. Compilation of available Data on Building Decontamination Alternatives: U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/036, 2005.

3 Clordisys. Chlorine Dioxide vs. Formaldehyde (http://www.clordisys.com/CDvsFormaldehyde.pdf), 50-035 Rev B, 2008.

4 U.S. EPA. Compatibility of Material and Electronic Equipment with Chlorine Dioxide Fumigation. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/037, 2010.

5 U.S. EPA. Compatibility of Material and Electronic Equipment with Methyl Bromide and Chlorine Dioxide Fumigation. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-12/664, 2012.

E: info@bioquell.com
W: www.bioquell.com

Bioquell UK
T: +44 (0)1264 835 835

Bioquell Ireland
T: +353 (0)61 603 622

Bioquell France
T: +33 (0)1 43 78 15 94

Bioquell USA
T: +1 (215) 682 0225

Bioquell Asia Pacific
T: +65 6592 5145

Bioquell China
T: +86 755 8631 0348