Comparison of hydrogen peroxide and chlorine dioxide as a method of vapour-based bio-decontamination

1.0 HEALTH AND SAFETY

1.1 Toxicity

Chlorine dioxide is roughly ten times as toxic as hydrogen peroxide. The OSHA permissible exposure limit (PEL[#]) is 0.1ppm, the 15 minute short term exposure limit (STEL[Ψ]) is 0.25ppm and the NIOSH 'immediately damaging to life and health (IDLH[ς]) is 5ppm', whereas hydrogen peroxide has a PEL of 1ppm, a STEL of 2ppm and an IDLH of 75ppm. Given the fact that the concentration of chlorine dioxide used for decontamination is typically 700ppm, a very small leak would instantly result in external concentrations above the IDLH ('immediate threat to life or would cause irreversible..health effects') of 5ppm, let alone the PEL or STEL.

Chlorine dioxide is a carcinogen and genotoxin.

When broken down by light and water, chlorine dioxide forms toxic chlorine gas and highly corrosive hydrochloric acid, respectively.

The lower levels of toxicity exhibited by hydrogen peroxide vapour; together with the lower concentrations within the target area and the 'lazy' (non diffusive) nature of the vapour alter the risk profile significantly. This was demonstrated practically during the SARS crisis in Singapore, where hospital ward decontaminations were performed in wards adjacent to occupied rooms.

When broken down, hydrogen peroxide forms water vapour and oxygen.

On an anecdotal level, it has been well documented that the main chlorine dioxide 'experts' who were sub-contracted to the EPA during the Hart building anthrax decontamination were sufficiently unsure of their ability to seal the building that they required the EPA to specifically indemnify them to the tune of $90m against third party injury by chlorine dioxide[i]. Leaks were detected in the Hart building decontamination.

1.2 Risk of explosion

The NIOSH website says the following about chlorine dioxide;

[#] Permissible exposure limit – the permissible exposure concentration calculated as an 8 hour time weighted average (TWA)

[Ψ] Short term exposure limit (UK) – the permissible short term exposure concentration calculated as a 15 minute TWA

[ς] 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.

"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 degrees C (212 degrees F). Airborne concentrations greater than 10 percent may explode", and goes on to say the following;

"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 the hydrogen peroxide solution used by BIOQUELL is negligible.

2.0 MATERIAL COMPATIBILITY

Chlorine dioxide is known to have significant material compatibility problems. The vast majority of materials may be corroded by chlorine dioxide, dependent on conditions, as shown by the table in Appendix B. The same table shows a list of materials, many in common usage, which show 'little or no resistance' to chlorine dioxide. Though hydrogen peroxide is also corrosive in its liquid form, 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 chlorine dioxide in the Capitol Hill anthrax decontamination has 'reasonable materials compatibility' as one of its titles. Under this 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 chlorine dioxide. During BIOQUELL's materials compatibility testing, a computer was subjected to 860 cycles, with no adverse affects. Furthermore, such is BIOQUELL's faith in the material compatibility of the process that sensitive and expensive hospital equipment has been bio-decontaminated both in Singapore, Continental Europe and in the UK, a list of which can be found in appendix C. All computer equipment was removed during the chlorine dioxide decontamination of Capitol Hill buildings

In addition to electronic equipment, hydrogen peroxide has excellent general material compatibility, as detailed in BIOQUELL's material compatibility document.

3.0 EFFICACY

Extensive testing was carried out prior to the bio-decontamination of the Hart building in which various *bacillus* spores (the most resistant micro-organisms according to the Spalding scale[ii]) were subjected to hydrogen peroxide and chlorine dioxide bio-decontamination cycles.

The tests concluded that chlorine dioxide requires a starting humidity of 70% and a concentration above 500ppm to achieve decontamination, although it was noted that starting humidity had a far greater influence on efficacy than did concentration. The efficacy of hydrogen peroxide was also tested, though there were no requirements on starting humidity.

Figures 1 and 2, below, show the reduction in bioburden of 6 different *bacillus* spores over time, having been subjected to a cycles at the recommended 70% relative humidity and a concentration of 620ppm and 750ppm, respectively. Figure 3 shows a test on the same spores using hydrogen peroxide.

The results clearly show that hydrogen peroxide is a more efficacious against the spores than either concentration of chlorine dioxide. The 620ppm chlorine dioxide test (Fig 1) failed to fully bio-deactivate 2 of the spores (worryingly, both anthrax) and took 8 hours to deactivate all but the *subtilis* spores. The higher concentration used in the 750ppm test significantly reduced the efficacy of the cycle. Only 2 of the spores were bio-deactivated, with the *bacillus anthracis ames* dying only after 12 hours. In striking contrast, the hydrogen peroxide cycle bio-deactivated all of the spores within 6 hours, and all but the *bacillus ames* and *sterne* were bio-deactivated within 1 hour.

The apparently suspect efficacy of chlorine dioxide was practically demonstrated during the bio-decontamination of the Hart building, where at least 3 attempts (as well as liquid chlorine dioxide) were needed to reduce the bio-burden to an acceptable level. It is unfortunate that the technology needed to deploy hydrogen peroxide on a large scale was not available at the time of the anthrax attacks.

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

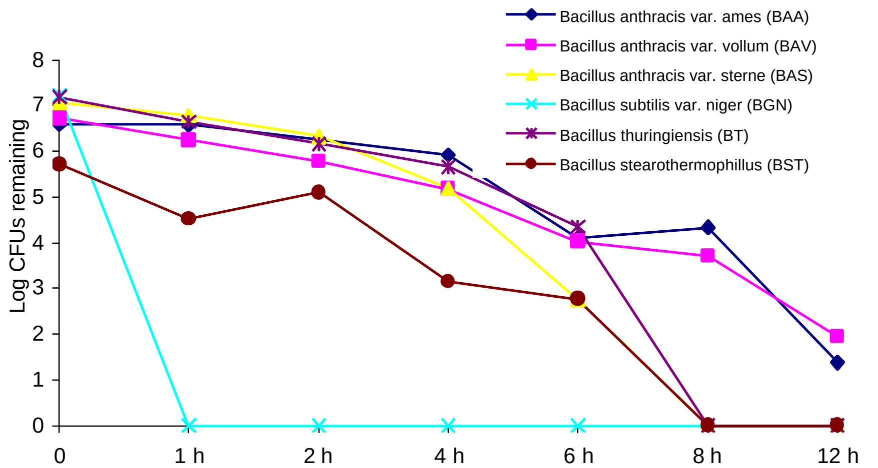


Fig 2 - Chlorine dioxide: Chart showing remining colony forming units (CFUs) after bio-decontamination cycle of 70% RH and 750ppm

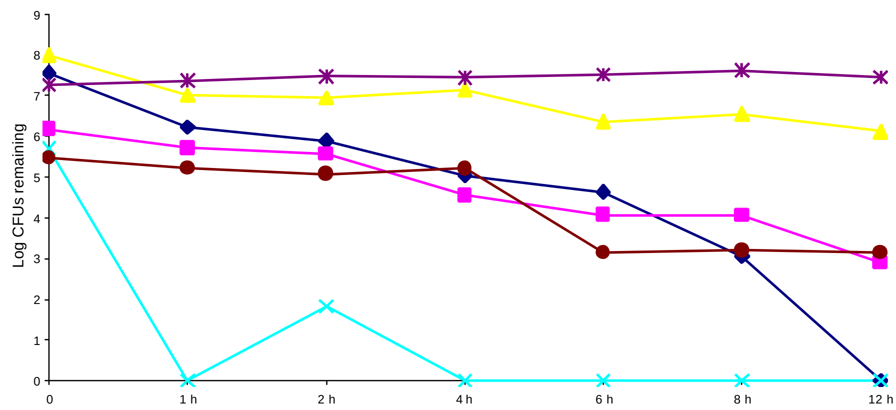
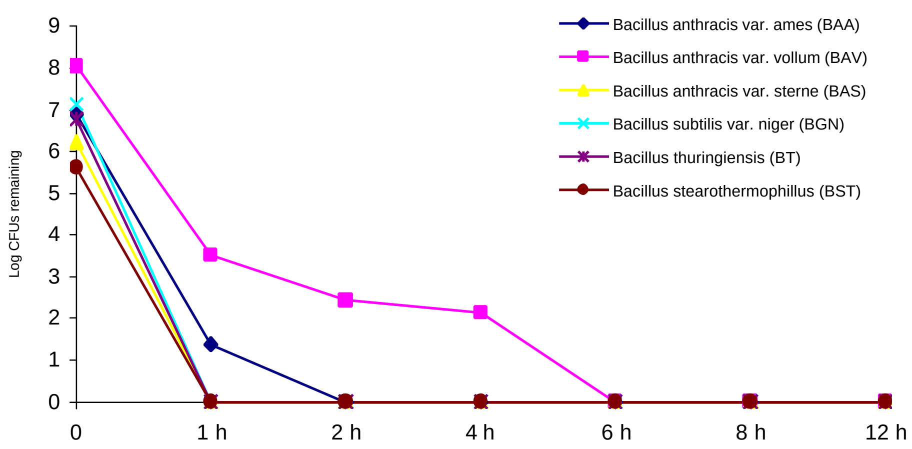


Fig 3 - Hydrogen peroxide: Chart showing remaining colony forming units after bio-decontamination



4.0 SIMPLICITY AND SPEED OF PROCESS

4.1 Starting conditions

Chlorine dioxide requires very specific starting conditions in order to be efficacious. Typically, a starting relative humidity of at least 70% and a temperature of 70F must be achieved before decontamination is started.

Hydrogen peroxide cycles can be run from a broad range of room temperature and relative humidity conditions.

4.2 Residues

Sodium bisulphate, the chemical typically used to neutralise chlorine dioxide, leaves a powdery residue which requires post decontamination cleaning, along with all the associated time and manpower costs it entails.

Hydrogen peroxide leaves no residue, breaking down into water vapour and oxygen

4.3 Out-gassing

According to the US EPA, chlorine dioxide is absorbed into materials and 'out-gasses' for an extended period after the cycle has been run. Though there is no qualitative data available, the same source describes hydrogen peroxide out-gassing as 'rapid'.

4.4 Downtime

The time and manpower needed to achieve the specific starting conditions and remove the residues left by chlorine dioxide are not required for hydrogen peroxide cycles.

The practical problems associated with this were evident with two aborted cycles during the Hart building decontamination process, where these conditions could not be achieved.

5.0 CONCLUSIONS

In the following categories hydrogen peroxide vapour is superior to chlorine dioxide as a means of bio-decontamination:

- Efficacy against *Bacillus* spores, known to be the most resistant micro-organism
- Health and safety, both in terms of toxicity and risk of explosion
- Materials compatibility
- Simplicity and speed, and therefore cost, of process

Appendix A – Tables showing log reductions for hydrogen peroxide and chlorine dioxide

Agent/Simulant **Hydrogen Peroxide**	Log initial inoculation	Log Reduction Factor					
		1 h	2 h	4 h	6 h	8 h	12 h
Bacillus anthracis var. ames (BAA)	6.88	5.5	6.88	6.88	6.88	6.88	6.88
Bacillus anthracis var. vollum (BAV)	8.05	4.53	5.62	5.92	8.05	8.05	8.05
Bacillus anthracis var. sterne (BAS)	6.23	6.23	6.23	6.23	6.23	6.23	6.23
Bacillus subtilis var. niger (BGN)	7.14	7.14	7.14	7.14	7.14	7.14	7.14
Bacillus thuringiensis (BT)	6.78	6.78	6.78	6.78	6.78	6.78	6.78
Bacillus stearothermophillus (BST)	5.62	5.62	5.62	5.62	5.62	5.62	5.62

Agent/Simulant **Chlorine Dioxide**	Log initial inoculation	Log Reduction Factor					
		1 h	2 h	4 h	6 h	8 h	12 h
Bacillus anthracis var. ames (BAA)	7.56	1.34	1.67	2.51	2.92	4.5	7.56
Bacillus anthracis var. vollum (BAV)	6.17	.45	.6	1.62	2.1	2.11	3.27
Bacillus anthracis var. sterne (BAS)	8.00	.99	1.05	.85	1.64	1.45	1.88
Bacillus subtilis var. niger (BGN)	5.71	5.71	3.88	5.71	5.71	5.71	5.71
Bacillus thuringiensis (BT)	7.26	-0.11	-0.21	-0.18	-0.26	-0.36	-0.2
Bacillus stearothermophillus (BST)	5.48	0.25	0.40	0.27	2.33	2.28	2.34

* These tests were conducted using ClO2 at the relative humidity and concentration recommended by the EPA and used during the bio-decontamination of the Hart Building.

Agent/Simulant* **Chlorine Dioxide**	Log initial inoculation	Log Reduction Factor					
		1 h	2 h	4 h	6 h	8 h	12 h
Bacillus anthracis var. ames (BAA)	6.60	0.02	0.34	0.68	2.49	2.26	5.22
Bacillus anthracis var. vollum (BAV)	6.72	0.48	0.94	1.54	2.69	3.01	4.77
Bacillus anthracis var. sterne (BAS)	7.06	0.28	0.73	1.87	4.30	7.06	7.06
Bacillus subtilis var. niger (BGN)	7.22	7.22	7.22	7.22	7.22	7.22	7.22
Bacillus thuringiensis (BT)	7.19	0.55	1.03	1.53	2.84	7.19	7.19
Bacillus stearothermophillus (BST)	5.72	1.20	0.62	2.57	2.95	5.72	5.72

Appendix B – Materials which exhibit poor resistance to chlorine dioxide

Chlorine dioxide is generally corrosive. Most materials display characteristics described as between 'resistant under certain conditions' and 'not resistant under any conditions' when subjected to chlorine dioxide, according to the DECHEMA corrosions handbook[iii]. Those materials listed below display characteristics described as between 'resistant only in a very restricted range of conditions' and 'not resistant under any conditions' in the same source.

Metallic
Aluminium
Aluminium alloys
Copper-zinc alloys (brass)
Unalloyed steels and cast steel
Unalloyed cast iron
Structural steels with up to 12% chromium
Ferritic chromium steels with more than 12% chromium
Austenitic chromium-nickel steels
Magnesium and magnesium alloys
Nickel
Nickel-chromium alloys
Nickel-copper alloys
Nickel-molybednum alloys
Tin and tin alloys
Zinc and zinc alloys
Cadmium and cadmium alloys

Non-metallic Inorganic Materials
Bitumenous compositions
Fats
Oils
Waxes
Furan resins
Polyamides
Polyacetals
Polyeurethanes
Alkyd resins
Epoxy resins
Amino resins
Silicones

Appendix C – List of sensitive medical equipment decontaminated using hydrogen peroxide

Hospitals:	Gleneagles Hospital
	Mt Elizabeth Hospital
	East Shore Hospital
Areas:	Fever Ward
	A&E Department
	Intensive Care Units
	High Dependency Care Units
Equipment that was subjected to the exposure	
	Siemens Servo 300C and 900C Ventilators
	Siemens Patient Monitors, System 8000, 7000 and 6000
	PICIS Clinical Information System comprising Compaq Personal Computers
	Planet LCD panels
	Tyco Puritan Bennett 800 Ventilator
	Baxtor Continuous Cardiac Output
	Terumo Infusion pumps
	Hewlett Packard (now Philips) Defibrillators
	Gambro Dialysis Machines
	Dinamap NIBP
	Hanau Operating Theatre Lights and controls
	Hewlett Packard Patient Monitors with various modules
	Grassby Infusion pumps
	Hillrom ICU and Electric Beds
	Seca Weighing scales
	Gomco Thoracic Suctions
	Hillrom Flatwalls and Flat Panels with Nurse Calls and Lighting controls
	Patient Data and HIS computers in Nurse Counters
	Hewlett Packard Central monitoring system in Nurse Counter
	Welch Allyn larngoscopes and diagnostic sets
	Telephones and Intercoms
	Non-Medical Equipment
	Fire sprinklers
	Heat Detectors
	Switches and Circuit breakers
	Lighting system
	Audio Visual monitors, speakers and amplierfiers.

References

[i] GAO, *Capitol hill Anthrax Incident,* Report to the Chairman, Committee on Finance, US Senate. June 2003

[ii] The Spalding Scale arranges classifications of micro-organisms in a descending scale. *Bacillus* spores proved the most resistant to bio-deactivation. Spaulding EH.Chemical disinfection and antisepsis in the Hospital. Journal of Hospital research. 1971, 9, 5-31

[iii] DECHEMA corrosion handbook: corrosive agents and their interactions with materials. Vol 11. Chlorine dioxide, seawater. 1. Corrosion. I. Kreysa, Gerhard; Eckermann, Reiner II. ISBN 1-56081-749-6 US

