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EDITORIAL

SARS-CoV-2 human disinfection chambers: a critical analysis

The Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) has spread across most of the world, overwhelming health systems, damaging economies, spreading fear and claiming lives. Due to the novel nature of the virus there is a lack of scientific data to aid with prediction, planning, containment and cure. The void created by the lack of information has rapidly driven innovation. The growing popularity of the human disinfection chamber is an example of rapid innovation in response to the global burden created by the Coronavirus Infectious Disease 2019 (COVID-19) pandemic.

Disinfection chambers have an entry point, an exit point, an enclosed chamber where the disinfection takes place, power supply, solvent supply, chemical chamber/mixer, air supply and compressor (typically but not always), and a spray mechanism. Optional features include in-chamber power outlets, lighting features, audio/video options, temperature scanners and chemical atomizers.

Information on virus stability on various surfaces is crucial in the evaluation of any disinfection process. The stability of SARS-CoV-2 under different temperatures and surface types measured at a temperature of 22°C and relative humidity of 65% is becoming clear [1]. Paper, for instance, had undetectable ('U') viable virus at 3 h; wood and cloth at 2 days; glass at 4 days; and the outer layer of a face mask at 7 days or longer (Table 1).

Whenever a new treatment, device or intervention is proposed, the immediate questions are efficacy ('does it work?'), health hazards ('is it harmful?') and safety hazards ('is it safe?').

The viricidal activity of several disinfectants has been ascertained (Table 2). Additionally, the Environmental Procession Agency (EPA) has published an extensive list of chemicals effective against SARS-CoV-2 [2]. Note that discrepancies do exist between various sources, underscoring the challenge of assessing viral traits and susceptibilities in laboratory settings.

Chloroxylenol, benzalkonium chloride and chlorine-based chemicals are examples of agents commonly utilized in disinfectant chambers. Coronaviruses are destroyed by ultraviolet C light (UV-C) exposure for 15 min [3]. The D90 value is an indication of the dose required to inactivate 90% of micro-organisms. The D90 values for different species of coronaviruses range between 7 and 241 J/m^2, with a mean of 67 J/m^2 demonstrating susceptibility of SARS-CoV-2 to UV-C [4].

When a chemical agent is used outside the manufacturer's recommendation, issues with safety and toxicity may be encountered. For instance, a disinfectant safe for topical application may become toxic when sprayed or aerosolized. With increased concentrations, atomization or aerosolization, the inhalation and absorption of the chemical significantly increase. The aerosolized particles are easily respirable travelling into the respiratory system to the alveoli. The increased duration and frequency of exposure (as in repeatedly going through a disinfection chamber to and from work, to and from lunch break, etc.) further magnifies the harmful effects. The chemicals can react with the mucosal lining causing irritation, swelling and ulceration in the respiratory tract. Some chemicals can be absorbed through the mucosa into the bloodstream and affect distant organ systems, e.g. central nervous system and gastrointestinal tract.

Direct aerosol contact with the cornea can cause irritation and irreversible damage. Skin irritation and damage are also common. If clothes are sprayed, skin exposure is prolonged until and unless the contaminated clothing is removed, and the skin thoroughly irrigated. UV radiation can cause damage to the eye and skin and is a known cause of skin cancer [5].

Some of the chemicals used in disinfection chambers have a low flash point, which can cause the chamber to ignite due to an electrical spark or increase in ambient temperature. Some disinfection chambers have power supply sockets within the chamber, further increasing the risk of combustion and electrical fire.

The various health hazards, safety hazards and toxicities of several disinfectants are summarized in Table 3.

Permissible exposure limits (PELs), time-weighted average (TWA) and short-term exposure limit (STEL) are not listed for benzalkonium chloride (quaternary ammonium–chloride compound). Yet, this chemical is far from non-toxic: the toxicity of benzalkonium chloride on eyes, skin and the respiratory system—both in animal studies and human exposures—is well-documented [6–11]. This is a classic example of where non-availability of PEL, TWA and STEL does not imply 'non-toxic'.

Table 1. SARS-CoV-2 stability on different surface types

Time	Virus titre (log $TCID_{50}$/ml)									
	Paper		Tissue paper		Wood		Cloth		Glass	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
0 min	4.76	0.10	5.48	0.10	5.66	0.39	4.84	0.17	5.83	0.04
30 min	2.18	0.05	2.19	0.17	3.84	0.39	2.84	0.24	5.81	0.27
3 h	U	–	U	–	3.41	0.26	2.21	–	5.14	0.05
6 h	U	–	U	–	2.47	0.23	2.25	0.08	5.06	0.32
1 day	U	–	U	–	2.07	–	2.07	–	3.48	0.37
2 days	U	–	U	–	U	–	U	–	2.44	0.19
4 days	U	–	U	–	U	–	U	–	U	–
7 days	U	–	U	–	U	–	U	–	U	–
Time	Banknote		Stainless steel		Plastic		Mask, inner layer		Mask, outer layer	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
0 min	6.05	0.34	5.80	0.02	5.81	0.03	5.88	0.69	5.78	0.10
30 min	5.83	0.29	5.23	0.05	5.83	0.04	5.84	0.18	5.75	0.08
3 h	4.77	0.07	5.09	0.04	5.33	0.22	5.24	0.08	5.11	0.29
6 h	4.04	0.29	5.24	0.08	4.68	0.10	5.01	0.50	4.97	0.51
1 day	3.29	0.60	4.85	0.20	3.89	0.33	4.21	0.08	4.73	0.05
2 days	2.47	0.23	4.44	0.20	2.76	0.10	3.16	0.07	4.20	0.07
4 days	U	–	3.26	0.10	2.27	0.09	2.47	0.28	3.71	0.50
7 days	U	–	U	–	U	–	U	–	2.79	0.46

U, undetected. From https://www.thelancet.com/journals/lanmic/article/PIIS2666-5247(20)30003-3/fulltext.

Ozonated water is widely used as a water and sewage sanitizer for its bactericidal properties. However, the EPA does not recommend the use of ozonated water for the disinfection of coronavirus. Ozonated water typically requires 10–30 min of contact time when used in water treatment. Ozone gas can be extremely irritating and toxic. Accidental inhalation of undiluted ozone can cause significant damage to the respiratory system, which can be fatal.

Several variations of disinfection chambers are already in use in response to the COVID-19 threat. A handful of manufacturers have incorporated engineering inputs to improve the safety and health profiles. The authors recently reviewed a disinfection chamber prototype that uses isopropanol (isopropyl alcohol; IPA) providing 20 s of contact time using a droplet size of <0.12 ml. The rationale for using IPA is the very rapid evaporation of the chemical upon exiting the chamber, with minimal residual effect on clothes or skin. Chamber users are requested to wear two masks with a waterproof outer layer as well as eye protection; however, the small droplet size may still result in inhalation of IPA.

The power supply is well-insulated with no active electrical charge within the chamber. There is a metal chain from the roof of the chamber to the floor upon entering the chamber through the plastic curtain. Contact with the rain chain dissipates any static electricity by grounding the human occupant. Given IPA's low flash point, an automated IPA spray was set to cool the chamber every 30 min to reduce the risk of combustion. However, periodic spraying of IPA lowered the temperature only by ~2–3°C. Chemical dispenser tanks must be placed in a safe environment, as the tanks themselves are susceptible to heat-related ignition and explosion. All it would take is a tiny spark of static electricity, a spark from engine ignition or a spark from nearby burning rubbish to set off an explosion.

Table 2. SARS-CoV-2 susceptibility to various disinfectants

Disinfectant (working concentration)	Virus titre (log $TCID_{50}$/ml)		
	5 min	15 min	30 min
Household bleach (1:49)	U	U	U
Household bleach (1:99)	U	U	U
Hand soap solution (1:49)	3.6[a]	U	U
Ethanol (70%)	U	U	U
Povidone-iodine (7.5%)	U	U	U
Chloroxylenol (0.05%)	U	U	U
Chlorhexidine (0.05%)	U	U	U
Benzalkonium chloride (0.1%)	U	U	U

U, undetected. From https://www.thelancet.com/journals/lanmic/article/PIIS2666-5247(20)30003-3/fulltext.
[a]Only one of the three independent triplicate reactions tested was positive.

We have attempted to summarize the efficacy, health hazards and safety aspects of commonly used chemicals in disinfection chambers. There are several key concepts:

1. When two or more chemicals are compounded together, the properties of the compound cannot be assumed to carry the same risk category as the individual chemicals. Assuming that a safe chemical plus safe chemical makes a safe compound is a dangerous assumption.
2. When a chemical or compound is dissolved in a solvent such as alcohol, the properties of the solvent have bearing on the dissolved compound. Safe chemical/compound plus solvent now also has the properties of the solvent.

Table 3. Comparison of commonly used chemical in disinfecting chambers[a–e]

Chemical	Flash point (°C)	LEL (%)	UEL (%)	IDHL (ppm)	OSHA PEL (ppm)	ACGIH TWA (ppm)	ACGIH STEL (ppm)	Reactivities	Health concerns—symptoms	Target organs
Isopropyl alcohol	10°C	2%	12.7% (90°C)	2000 ppm (10% LEL)	400 ppm (980 mg/m^3)	200 ppm	400 ppm	Strong oxidizer	Irritation of eyes, nose, throat, upper respiratory tract Drowsiness, dizziness headache Dry skin	
Chlorine	Non-flammable	N/A	N/A	10 ppm	1 ppm (3 mg/m^3)	0.5 ppm	1 ppm	Strong oxidizer Explosive with turpentine, fuel, ammonia	Burning of eyes, nose, mouth Lacrimation and rhinorrhoea Cough and choking Nausea, vomiting, headache, dizziness Pulmonary oedema, pneumonia Hypoxia Dermatitis	Eyes Skin Respiratory system
Benzalkonium chloride (quaternary ammonium)	Flammable	N/L	N/L	N/L	N/L	N/L	N/L	Corrosive	Irritation of eyes, skin and mucosa Skin hypersensitivity Respiratory irritation Acute toxicity	Eyes Skin Respiratory system
Hydrogen peroxide	Non-combustible	N/A	N/A	75 ppm	1 ppm (1.4 mg/m$^{3)}$	1 ppm	Not available	Powerful oxidizer with selective metals	Irritation of eye, nose and throat Corneal ulcers Skin damage and bleaching of hair	
Ozone	Non-flammable	N/A	N/A	5 ppm	0.1 ppm (0.2 mg/m$^{3)}$	0.20 ppm (for <2 h of exposure)	Not available	Powerful oxidizer with selective material	Irritation of eye and mucus membrane Pulmonary oedema Chronic respiratory disease	Eyes Respiratory system
Chloroxylenol	Potentially flammable	N/L	N/L	N/L	N/L	N/L	N/L	Stable under normal conditions	Irritation and corrosion of skin and eyes Skin hypersensitivity	Eyes Skin Respiratory system
Poly (hexamethylene biguanide) hydrochloride	No data available	N/L	N/L	N/L	N/L	N/L	N/L	Stable under normal conditions	Eye damage Skin irritation Skin hypersensitivity	Eyes Skin

Table 3. Continued

Chemical	Flash point (°C)	LEL (%)	UEL (%)	IDHL (ppm)	OSHA PEL (ppm)	ACGIH TWA (ppm)	ACGIH STEL (ppm)	Reactivities	Health concerns—symptoms	Target organs
Acetic acid	39°C	4%	19.9% (93°C)	50 ppm	10 ppm (25 mg/m³)	10 ppm	15 ppm	Strong oxidizer	Irritation of eye, skin, nose, throat Damage to skin and eyes Discolouration of skin Skin hypersensitivity Dental erosion Pharyngeal oedema, chronic bronchitis	Eyes Skin Respiratory system

LEL, lower explosive limit; UEL, upper explosive limit; IDHL, immediately dangerous to health or life; PEL, permissible exposure limit; TWA, time-weighted average; STEL, short-term exposure limit; OSHA, Occupational Safety and Health Administration; ACGIH, American Conference of Governmental Industrial Hygienist; N/L, no limit; N/A, not applicable.
[a]ACGIH TLVs and BEIs for Chemical Substances and Physical Agents.
[b]NIOSH Pocket Guide to Chemical Hazards, Department of Health and Human Services (CDC and NIOSH).
[c]https://www.fishersci.com/store/msds?partNumber=AC263820010&productDescription=BENZALKONIUMCHLORIDE%2C+50 + 1LT&vendorId=VN00032119&countryCode=US&language=en.
[d]https://pubchem.ncbi.nlm.nih.gov/compound/Chloroxylenol#section=Acute-Effects.
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3. If safety limits or exposure limits have not been established for a given chemical or compound, it does not mean the chemical or compound is safe.
4. Most of the research is on exposure occurring as an accidental consequence of existing work activity, and where engineering controls, administrative controls and personal protective equipment (PPE) are in place to minimize exposure. This is a very different scenario from walking into a spray chamber.
5. The main routes of toxic exposure include inhalation, absorption and ingestion [12]. In the context of a disinfection chamber, inhalation and absorption are most important.
6. Changing the chemical's formulation and route of administration may drastically affect its safety profile. A chemical may be safe when applied topically in liquid form, but extremely toxic when atomized and inhaled.

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