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Review Article

Innovative Disinfectant Spraying Methods to Prevent Spread of Infectious Organisms

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Abstract

A pandemic health crisis has occurred throughout the world due to COVID-19 since early 2019. Several governments are targeting the control of community spread by spraying a broad range of chemical disinfectants at crowded indoor and outdoor public spaces which are likely to be highly contaminated. This has led to the use of a broad range of chemical disinfectants in public areas. The conventional disinfectant spraying practice with the existing machinery need high manpower and logistics are energy intensive. Hence there is a need for a convenient and affordable technique to spray disinfectants for efficient protection from any type of virus. To overcome the demerits of the conventional practices, an innovative, practical and economical approach is discussed, taking cognizance of the regulatory framework. The described techniques are effective in the current and would also be useful in the post lockdown pandemic periods to improve overall sanitary practices and hygiene awareness, worldwide.

Keywords: Disinfectants; Pouches; Stickers; Exhaust Fan; Vehicles; Plastic Can

- Innovative models (conceptual) were designed to spray disinfects.
- These techniques will be effective in the current as well as post lockdown pandemic era.
- As a social responsibility to improve overall sanitary practices and hygiene awareness, worldwide as required.

Introduction

Microorganisms are ubiquitous. Most microorganisms are non-pathogenic but some are opportunistic and pathogenic. Pathogenic microorganisms can infect by entering the body through any medium such as soil, water, air and physical contacts [26,57]. Some of these microorganisms may be responsible for epidemics and pandemics. There are several instances of epidemics and pandemics in the past. Severe Acute Respiratory Syndrome (SARS) CoV-2, COVID-19 is the recent example of a viral pandemic.

In humans, coronaviruses are known to cause respiratory infections like Middle East Respiratory Syndrome (MERS), Severe Acute Respiratory Syndrome (SARS), and SARS- CoV-2 or COVID-19. Structurally the coronavirus is spherical with an average diameter of around 120 nm and consist of an envelope of a lipid bilayer with glycoproteins (outside as ‘spikes’) and transmembrane proteins [23,65]. This viral infection was first identified at Wuhan, China in December 2019. A Public Health Emergency of International Concern (PHEIC) was declared by the World Health Organization (WHO) in January 2020 and pandemic in March 2020. Governments scaled up their testing, contact tracing and isolation facilities to tackle the outbreak. A recent study has shown that SARS-CoV-2 transmits via aerosols [55] and the virus persists in air for 3 hours, as well as for 9 days on nonporous surfaces like chrome steel and plastic surfaces [23,42,48,50,64].

Due to the pandemic, all the countries imposed restrictions on mobility and social gathering to curtail the spread of COVID-19. Several governments used chemical disinfectant sprays to disinfect the contaminated areas like houses, markets, hospitals, roads and other public spaces. These disinfectant chemicals are from different groups and categorized into alcohols, aldehydes and quaternary ammonium compounds, among others. The United States Environmental Protection Agency (EPA) has recommended standard practices, list of disinfectants and tools to control the spread of the virus. Due to the high infectivity rate of SARS-CoV-2, it's cumbersome to design and execute a disinfectant spraying mechanism for highly contaminated public spaces.

There are many disinfectant spraying techniques practiced throughout the world as per WHO's recommendations [59,60]. Efforts are taken by governments and local authorities to conduct disinfection campaigns in public sectors [24,65]. Most of these techniques incur a significant cost, manpower and space. To overcome these hurdles, this present review proposes novel spraying mechanisms.

Disinfectants and its mode of action

Disinfection is defined as the selective elimination or inhibition of the growth of [4] of microorganisms (desired or undesired) to prevent their transmission. The chemical components (natural or synthetic) involved in this process are called disinfectants [41]. Disinfection is classified into physical and chemical processes. A physical process involves the use of heat, radiation, filtration etc. Whereas a chemical process consists of use of various classes of chemical agents (Figure 1). Usually the disinfectants are applied on surfaces with a specific concentration and time of exposure. Disinfectants act on targeted microbes in different ways by (a) damaging the cell membrane, (b) through membrane permeability, (c) downregulating protein and nucleic acid synthesis. Figure 2 (EN 14476:2013) [3,16,28].

Figure 1: Classification of disinfectants: Physical and chemical disinfectants A physical process involves the use of heat, radiation, filtration and chemical process consists of use of various classes of chemical agents.

Figure 2: Mode of action of disinfectants: Disinfectants act on targeted microbes in different ways by (A) damaging the cell membrane, (B) through membrane permeability, (C) downregulating protein and nucleic acid synthesis.

Traditional and currently used disinfectants

Globally, the use of surface disinfectants is in demand. In this pandemic, the usage has increased significantly in hospitals and public places. Most of the chemical agents are biocidal in nature with a broad-spectrum of activity against a wide variety of microorganisms. These are categorized into static and -cidal drug types based on the mode of action on targets. Those which deal with the inhibition of the growth or multiplication of microorganisms are known as "Static" in action and referred as bacteriostatic, fungistatic and sporostatic, according to the target organisms. Whereas, the chemical agents which are lethal to the target microorganism are known to be "-Cidal" in action and are referred to as sporicidal, virucidal and bactericidal, again according to the organisms targeted [28]. Chemical structures and uses of biocides are given in table 1.

Alcohol

Alcohol, including ethanol (ethyl alcohol) (EPA registration number (42964-17, 62472-2) (EPA 2020), act by disrupting the cellular membranes by solubilising the lipids, and denaturing the membrane bound proteins (by acting on S-H functional groups). Ethyl and isopropyl alcohols are widely used alcohols for their effective biocidal activity [13,14,67].

Disinfectants	Active ingredients	Chemical formula	Mode of action
Alcohols	Ethanol	C_2H_6O	Disinfection Antisepsis Preservation [13,20-23,36,47,52,67]
	Isopropanol	C_3H_8O	
Aldehydes	Glutaraldehyde	$C_5H_8O_2$	Disinfection Sterilization Preservation [25, 26, 44, 45]
	Formaldehyde	CH_2O	
Phenols and Bisphenols	Carbolic acid	C_6H_6O	Disinfection Antisepsis Preservation Deodorant Antiplaque agent [29, 38, 67]
	Triclosan	$C_{12}H_7Cl_3O_2$	
	Hexachlorophene	$C_{13}H_6Cl_6O_2$	
Chlorine and chlorine compounds	Hypochlorites	ClO_-	Disinfection Antisepsis Preservation Antiplaque agent [17, 35, 37, 62, 67, 68]
	Chlorine dioxide	ClO_2	
Peroxygens	Hydrogen peroxide	H_2O_2	Disinfection Antisepsis [67]
	Peracetic acid (PAA)	$C_2H_4O_3$	
Anilides (phenylamides)	Triclocarban	$C1_3H_9Cl_3N_2O$	Disinfection Antisepsis
Biguanides	Chlorhexidine	$C_{22}H_{30}Cl_2N_{10}$	Disinfection Antisepsis Preservation Antiplaque agent
	Alexidine	$C_{26}H_{56}N_{10}$	
	Biguanides	$C_2H_7N_5$	
Quaternary ammonium compounds (quats or QACs)	Alkyl dimethyl benzyl ammonium chloride	$C_{22}H_40N+$	Disinfection Antisepsis Preservation Cleaning [12,18,31,66,67]
	Benzyl dimethyl octyl ammonium chloride	$C_{17}H_30ClN$	
	Benzyl dimethyl octyl ammonium chloride	$C_{22}H_{48}ClN$	
	Cetrimide	$C_{17}H_{38}BrN$	

Table 1: Chemical structures and uses of biocides.

Ethanol has been reported to have a stronger and broader spectrum virucidal activity and is used mostly in alcohol-based hand sanitization rubs and marketed under different brand names [21]. These alcohols at a concentration of 70-80% are effective against a wide range of bacterial species (*Bacillus* sp., *Pseudomonas* sp. *et al.*), viruses (calicivirus (FCV), poliovirus, polyomavirus, hepatitis virus (HAV) and animal disease virus (FMDV)) [9,20,22,27,43].

Microbial activity of ethanol is optimal at the dilution of 70-80% and is superior than isopropanol for use against hydrophilic viruses e.g. human immunodeficiency virus (HIV), rotavirus and coronaviruses whereas isopropanol is effective against lipophilic viruses e.g. hepatitis A virus (HAV) and poliovirus.

World Health Organization [56,59,60] listed three terminology by European Committee for Standardisation technical committee on virucidal activity. The first list shows the activity against enveloped viruses, second for limited spectrum virucidal activity and third for virucidal activity [20] which incorporates enveloped viruses like adenoviruses, noroviruses and rotaviruses viruses relevant in human, respectively [61]. They have been studied at different concentrations of ethanol (45%, 70%, 77% and 95%) for efficacy at duration of 30s [36,47,52,67]. It has been recently reported that ethanol and isopropanol are efficient for inactivating coronavirus at 70-90% concentrations within 30s [23,58] by membrane damage and denaturing of viral membrane proteins.

Aldehydes

Aldehyde is a compound with –CHO (aldehyde or formyl group) functional group. Glutaraldehyde and formaldehyde are the best examples of disinfectant components. Glutaraldehyde solution at 0.1% to 1.0% concentration acts as a biocide and is mostly used in disinfection process, fixation, and sterilization. Formaldehyde at 0.2% - 0.4% concentration acts as a disinfectant and is used in cosmetics, hair shampoos and antiseptic products. The solid form of paraformaldehyde is used as a source for formaldehyde vapours for the disinfection of labs/ rooms [44,45,67].

Phenols and bisphenols

Phenols or phenolics, are a class of chemicals having one or more hydroxyl groups (—OH) at the aromatic hydrocarbon group. Based on the number of phenol units in the molecule phenolic compounds are simple phenols or polyphenols. Phenolic compounds are synthesized by plants and microorganisms, and also manufactured by chemical industries. Phenolics (EPA identification number 3862-179) [29] at 1-2% concentration damage cellular membrane and are effective against enveloped viruses, fungi, and bacteria. They are more effective when combined with organic materials – and commercially these are available as cresols, hexachlorophene, alkyl- and chloro derivatives and diphenyls [44]. In many countries, phenolic compounds were not used as disinfectants due to the toxicity issues [29,30,38,56,59,60,67].

Chlorine and compounds

Sodium hypochlorite (EPA registration number – 56392-10, 67619-17, 67619-30, 67619- USEPA, 2020) is reported as an effective disinfectant [54,67] at 1-10% concentration against bacteria, viruses, and fungi. Sodium hypochlorite affects the viral or bacterial cytoplasmic membrane integrity, enzymatic inhibition, alterations in biosynthetic cellular metabolism and degradation of phospholipids by lipid peroxidation due to its high pH-based activity [67]. It is available as commercial products like Clorox and sodium hypochlorite solution (8.25%) [1,17,35,37,49,68].

Peroxygens

Peroxygens like hydrogen peroxide (3%), EPA registration number (66171-103, 45745-11, 65402-9) (EPA 2020) (USEPA, 2020) are unaffected by the addition of organic matter and salts. Hydrogen peroxide is an example for the peroxygens and is effective at the concentration of 3% or 0.5% with EPA registration number (66171-103, 45745-11, 65402-9) (EPA, 2020) [67]. Examples of available commercial products are VigorOx 15/10 and Peroxy HDOX and are effectively used as disinfectant and antiseptic.

Quaternary ammonium compounds (QACs)

QACs are reported to be less toxic. They are membrane-active agents and they are more effective against bacteria, yeast by interacting with the cytoplasmic membrane and the plasma membrane. Chemically they are positively charged cationic surfactants which affect cell wall and membranes by binding readily to the negatively charged surfaces of most microbes [6]. They are mostly used chemicals in the industries.QACs are used in wipes and sprays, and also as additives in soaps and non-alcohol-based hand sanitizers due to their ability to eradicate surface bacteria and viruses such as influenza by disrupting their phospholipid membrane [19,63]. Less than 1% concentration is effective against coronaviruses with an exposure of around a minute [23].

QACs have also been reported to interact with intracellular targets and bind to DNA. (EPA registration number 675-54, 6836-70, 6836-75, 6836-77 (EPA 2020) (USEPA, 2020). They are generally fungicidal, bacteriocidal, and virucidal against lipophilic (enveloped) viruses [12,31,66]. Available commercial products which are in use as QAC disinfectants are Lysol/ (maximum use), Lonza, Maquat 256-MN, Maquat 128-MN, Maquat 64-MN, Maquat 32-MNL and Sterilex Ultra etc. [12,18,67].

Anilides (Phenylamides)

The anilides have also been reported as antiseptics, but they are rarely used in the clinics. Triclocarban (TCC; 3,4,4′-triclorocarbanilide) is used in soaps and deodorants.

Anilides are active against gram-positive bacteria but less effective against gram-negative bacteria and fungi. These chemicals affect the cytoplasmic membranes, which eventually lead to cell death [56,59,60].

Natural disinfectants

A study on influenza viruses found that cleaning with a 10% solution of malt vinegar was effective [67]. Recently EPA added few natural disinfectants to their list of approved disinfectants to fight against COVID-19. A product cleanwell (Botanical disinfectant) consists of thymol, which is a component found in herb thyme oil Curcumin the compound present in turmeric spice also has antimicrobial properties [54,67].

Conceptual disinfectant spraying methods

Available spraying methods and its limitations

Disinfection of public roads done by wide range of disinfectants are employed by various organizations and governments as per WHO recommendations. Tankers, trucks, and drones are used as disinfectant carrier unit to spray at infected areas. The types of machines employed are hydraulic sweeping machine, mini sweep machine, truck mounted road machine, battery operated manual road machine etc. Although these techniques proved to be effective but there have been limitations in reaching specific areas periodically and requires a lot of manpower, electrical, fuel consumption and cost [5,49,62].

Due to the limitations in conventional spraying methods, we are proposing a possible way of spraying methods under automated process. This can be operated without the use of high energy, manpower and machinery. Spraying of disinfectants achieved through public vehicles and exhaust fans for disinfecting the larger and smaller areas, where big machinery could not be deployed.

Mode of application of disinfectants

There are various techniques to apply liquid and solid disinfectants in large and common public areas such as roads, parks, etc. With recommended concentrations, liquid disinfectants can be sprayed using public vehicles like two or four wheelers with a piston pump and dripping assembly. Solid disinfectants can be applied or sprayed by sublimation principle. (Figure 3).

Figure 3: Water bottle disinfectant spray by vehicles (piston pump) A) Disinfectant water can model with piston- pump assembly, B) Spraying the disinfectants in the form of vapours using automobiles.

Promising approaches to disinfect coronavirus

Liquid disinfectants

Disinfectant spray by vehicles using piston pump assembly

As shown in Figure 3A and B, the disinfectants filled assembly can be fixed with any automobile. Disinfectants can be sprayed as a fine mist on roads or streets when the vehicle moves. The advantages of this method are that larger populations can be engaged during their regular commute to disinfect common areas repeatedly and regularly without any additional energy and cost consumption. The assembly consists of a switch and pressure-based pump and which is connected to conducting plastic tube which is useful to build the vacuum inside the cylinder. Once the vehicle started, the trigger lever activates the pressure pump and helps the suction pump to draw the liquid disinfectant from the cylinder and flows outside

Disinfectant spray by dripping assembly with fan

In another method, disinfectant sprayed with the help of dripping control unit assisted with fan (Figure 4A). In this assembly, liquid disinfectant flow through the control unit and the fan helps to sprinkle the mist effectively on roads because of fan blades. (Figure 4B).

Figure 4: A) Water tank disinfectant dripping assembly assisted with exhaust fan to spray effectively, B) Sprinkling of disinfectant assembly with vehicles.

Reducing air pollution particulate matters (PM2.5 and PM10) by disinfectants spray

Automobile tailpipe exhausts are major air pollution contributors because of the internal combustion of fossil fuels which contains toxic gases like carbon monoxide, hydrocarbons, nitric oxide (NOx) and sulfur oxide (SOx), lead (Pb) and particulate matter [10]. As per air quality guideline suggested by WHO, that PM2.5 not exceed 10 $\mu g/m^3$ annual mean, or 25 $\mu g/m^3$ 24-hour mean and PM10 not exceed 20 $\mu g/m^3$ annual mean, or 50 $\mu g/m^3$ 24-hour mean (WHO). In China and other countries, the water spray geoengineering method helped them to reduce particulate matter in the air [46]. In view of this, if the disinfectant spray unit is attached near to the automobile tailpipe, a mist of disinfectant will mix with exhaust gas and bring down the particular matters and other pollutants (Figure 5). Additionally, this will help to disinfect the roads also.

Figure 5: Reducing the air pollution and disinfection of roads.

Solid disinfectants

Disinfectant spread by exhaust using porous pouches

Natural or synthetic disinfectants can be mixed with a solidifier to make a solid bar disinfectant and packed in a porous pouch. This solid bar disinfectant can be placed in exhaust units of homes, hospitals, offices and other public places.

The mode of action works on the principle of sublimation. This strategy could help us in preventing the spread of infectious germs in the surrounding environment. These pouches could be placed or installed (Figure 6) with an exhaust fan, or even on moving vehicles, home decor items, wind chains, washrooms and doors.

Figure 6: Natural or synthetic solid disinfectants fixed in an exhaust fan at home, offices and other public places.

Disinfectant spread by rotating models on vehicle

Disinfectant pouches could be attached to the spokes of a bicycle as shown in (Figure 7A) or front mudguard or side deck of two-wheelers (Figure 7B). This model is highly effective, easy to operate and disinfects small roads that are inaccessible by automobiles.

Figure 7: Solid disinfectants in pouches (A) Disinfectant pouch fixed on bicycle spoke (B) on scooter.

Wind mill disinfectant spreader with energy storing modules at road side

As shown in figure 8, solid disinfectant chemicals are attached to the windmill shape fan blades and installed at roadside. During the wind or vehicle movement, fan blades will start rotating and spread the disinfectant effectively. Additionally, energy will be stored in the modules because of fan rotation. Stored energy from multiple modules can be utilised for powering traffic signals, lighting, irrigating plants and road cleaning.

Figure 8: Disinfectant spreader rotating models with energy storing modules at roadside.

Production, implementation, limitations, and regulation

These disinfectant spraying approaches requires an administrative and an economic bolstering from public and government authority for implementation in society. Sponsors would be municipal corporations, government authorities, NGOs, private organizations, and philanthropists etc. Spraying prototype production may be managed from small scale plastic manufacturing companies or recycling units. Distribution of disinfectants with specific concentration can be done through different public places such as markets, private or government organization, cooperative housing societies, petrol filling stations etc. It's mandatory to draft proper safety guidelines for implementation and regulation of chemical dosage of each disinfectant. Safety policies or guidelines need to be drafted by regulatory bodies to disinfect public places regularly as well as safe to public.

Conclusion and Path Forward

It is required to study disinfection efficacy and various factors such as area, time, concentration, container type etc. for the daily workflow from the risk and spread of COVID-19 infection. The novel spraying disinfectant techniques described in the article are effective, easy to operate, affordable, portable and accessible to every corner of the nation, the streets and roads where big machineries are difficult to reach. Spraying mist would reduce the usage of disinfectant dosage and increase the effectiveness by occupying large surfaces with minimum quantity. Solid disinfectants kept in exhaust or automobiles will be helpful to reduce contaminants in the surrounding area. These techniques are economically feasible because considerably less energy and manpower is required. The development of environmentally sustainable processes are required with respect to the waste management and relevant machineries. The described techniques are effective in the current and would also be useful in the post lockdown pandemic periods to improve overall sanitary practices and hygiene awareness, worldwide. This research paves a new way for good hygienic practices for mankind to fight against coronavirus as well as any future pandemic.

Author Contribution

Both authors contributed equally to this manuscript.

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