Minireview Article

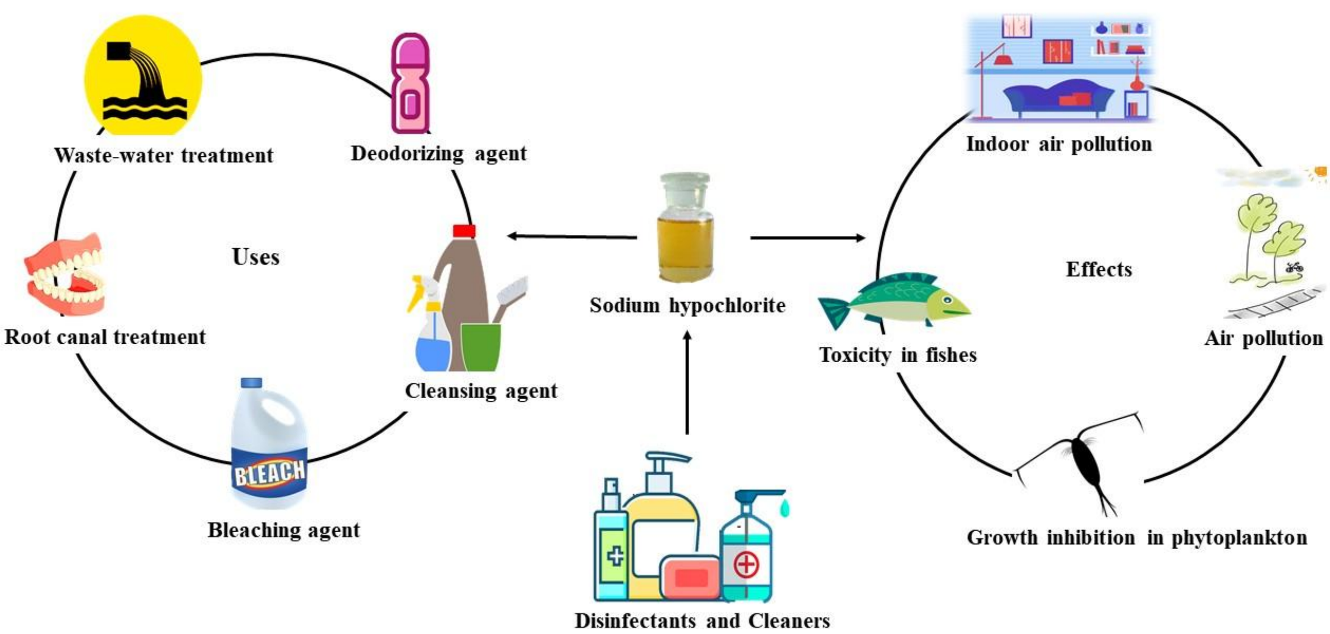
Impacts of Sodium Hypochlorite on Humans and Environment

Abstract

Sodium hypochlorite (NaOCl) usage is increased extraordinarily after COVID-19. After lockdown, NaOCl is used as a disinfectant at every possible public and private place. Hospitals and Institutions were using it for the same purpose. In this study, NaOCl chemistry is investigated. Its impact on humans and the environment is also analyzed from the available literature. Although, some immediately recent research papers are also considered and mentioned in this paper. This paper also encapsulates information about NaOCl usage, advantage, comparison with other disinfectants, importance, precautions, etc. This study concludes the standardized use of NaOCland also recommends the policy required for its use.

Keywords: Sodium hypochlorite, COVID-19, Disinfectant, Human, Environment

Fig 1: Graphical Abstract



Research Highlights

• Sodium hypochlorite (NaOCl) usage drastically increased during COVID-19.

• NaOCl shows visible impacts on humans and the environment.

• Policy for usage of NaOCl required considerable changes due to its negative impact on aquatic life, and other life forms.

• NaOCl could drag attention in the future due to its highly reactive and hazardous characteristics.

1. Introduction

1.1 COVID-19 Outbreak

The World Health Organization (WHO) on the 11th of March 2020 announced the COVID-19 outbreak as a global pandemic (WHO., 2020). This is on account of various cases of local transmission across all six WHO regions (Yelin et al., 2020). The transmission of the infection occurs in two forms namely Direct Transmission and Indirect Transmission. The spread of infection is rapid and often grave when norms of social and physical distancing between the infected and non-infected individuals take place. However, this transmission occurs through various means which include direct transmission through droplets out of coughing, sneezing, spitting, body-liquids, etc while indirect transmission is very prevalent through touching of various surfaces (Boone & Gerba, 2007; Brankston et al., 2007; Jayaweera et al., 2020; Tellier, 2006; J. Wang & Du, 2020). COVID-19 outbreak comes as a surprise to all humankind and the wide spreading of the disease and the exponential increase in the number of infected cases makes this disease a novel one. Scientists and researchers all around the scientific community are in their rapid phase of research, exploration, and assessment of various vaccines, given the urgency and seriousness of the situation. Thus, all individuals have no other option left to rely on the widely used proverb, “prevention is better than cure” as rightly advised by the Australian Government Department of Health, 2020 similar to many other governmental institutions. Thus, in tackling novel COVID-19, certain rules and guidelines like social distancing, sanitization, disinfection, restricted movement, masking oneself, one-hand distance in public spaces, etc are some of the devised mechanisms to avoid the probable chances of spread of the viral disease (Jayaweera et al., 2020).

1.2 Increased use of disinfectant in COVID-19

In the wake of the global pandemic, among all other disinfecting agents, sanitisers have found their place in every nook and corner of the global health system the possible transmission of the virus through direct and indirect transmission sources. Thus, the relevance becomes much more important given the fact of its usefulness and the demand of the situation. Therefore, we can easily locate different types of sanitisers in the markets. The various types of sanitizers are classified into alcohol-based or alcohol-free depending on the active ingredient used. Alcohol-based sanitisers include ethanol, isopropanol, n-propanol, etc, while the alcohol-free options are benzal aluminium chloride (BAC), triclosan, etc (Pickering et al., 2011; Tamimi et al., 2014). Along with following social distancing norms, wearing protective wears like gloves, masks, and maintenance of proper hygiene in addition to the use of disinfecting agents like Sodium hypochlorite and many others that sterilize and sanitize surfaces of various objects, houses, and institutions (Fathizadeh et al., 2020). Given the extent of use and easy reachability of various disinfectants, the importance of their wise selection and subsequent utilization in daily life becomes essential. This study extensively emphasizes an overview of the use, impact, and effect of Sodium Hypochlorite on human health and the environment in the wake of the COVID-19 pandemic situation. Disinfectants are chemicals used on nonliving or abiotic surfaces for the reduction of the count of microbes on the surface like Sodium hypochlorite. A sanitiser is a mixture consisting of disinfectant along with detergent or dirt-removing chemicals e.g. Alcohol-based hand sanitisers. It is intended to be applied for reducing microbial and dirt entities on a particular surface. Cleaners are any chemical with which we can clean a surface and can remove dirt or dust particles like Acidic-Hydrochloric acid, Neutral- Non-ionic surfactants, Basic-Sodium hydroxide or potassium hydroxide.(Chauret et al., 2005; Lages et al., 2008)

2. Sodium hypochlorite

Sodium hypochlorite or Sodium chloride oxide is chemically sodium oxychloride. It is also called liquid bleach or bleach when dissolved in water. It is often utilized as a disinfectant and also a bleaching agent. Household bleach is, typically a solution containing 3-8% sodium hypochlorite and 0.01-0.05% sodium hydroxide (Slaughter et al., 2019). It is corrosive to some metals and is a skin and eye irritant too. The compound is stable but when it comes in contact with strong acids it releases poisonous chlorine gas. It is photosensitive too along with having reactivity (Slaughter et al., 2019). It is used in surface cleaning, water disinfection, and purification, washing the root canal system. Specifically, due to antimicrobial activity and pulpal dissolution activity, it is widely used as a popular agent for the irrigation of the root canal system in solution form (Estrela et al., 2002). Sodium hypochlorite has destaining properties and it is used to eliminate mould stains, dental stains caused by fluorosis (Cárdenas-Bahena et al., 2012). As per the recommendation of the World Health Organisation (WHO,2020), we need to correctly and consistently disinfect the environment as the droplets of any affected person if present on any surface can be a new source of infection for an unaffected person. Intensive cleaning with water, detergent, and sodium hypochlorite (a common household and hospital disinfectant) are quite sufficient and effective measures. Sodium Hypochlorite gets inactivated when comes in contact with organic matter. The surface should be cleaned with soap and water along with scrubbing action and then if it is applied the chances of complete disinfection become more successful. Corrosion of metals, asthma, skin irritation, and mucous membrane damage are also associated with a high concentration of chlorine (Slaughter et al., 2019). Commercial production of sodium hypochlorite in different concentrations is dependent on various factors such as place of manufacturing, consumer demand, usage requirements, and government policies.

Sodium hypochlorite shows different behaviour in terms of its effectiveness and reactivity under different concentrations. Sodium hypochlorite at 0.5% concentration with and without colour additives is effective against Staphylococcus aureus and stands good on the criteria of the Environmental Protection Agency (EPA) for disinfectant success (Dellanno et al., 2009; Tyan et al., 2018). Whereas in the case of human coronavirus 229E, the combination of 0.5% sodium hypochlorite solution with the colour additive resulted in successful viral inactivation (Dellanno et al., 2009). The typical concentration of a 1% sodium hypochlorite solution is often used for disinfection purposes. Sodium hypochlorite is a common biocidal agent and at 0.21% concentration is effective against Mouse Hepatitis Virus (MHV) Strain MHV-1 with an exposure time of 30 seconds and having $\geq$ 4.0 reduction in viral infectivity (log10)(Dellanno et al., 2009). The Canine Coronavirus (CCoV) has extremely low stability in the environment because of alternation in pH levels of colloids and ions present in faeces that results in the inactivation of the virus (Pratelli, 2008; Tennant et al., 1994). On the surface of stainless steel, the disinfectant sodium hypochlorite having 0.5% concentration is effective in disinfecting from HCoV Strain 229E (Sattar et al., 1989) whereas 0.06% concentration is effective against TGEV on stainless steel surface (Hulkower et al., 2011).

2.1 Chemistry of Sodium Hypochlorite (NaOCl)

The chemical Sodium hypochlorite is well-established bleaching, disinfecting, and oxidizing agent due to which it is suitable for a wide range of applications. Sodium hypochlorite consists of Na+ cation and an (OCl^- or CLO-) hypochlorite anion and can be said as the sodium salt of hypochlorous acid as it is produced along with sodium chloride and water by the reaction between chlorine gas and Sodium hydroxide (Kirihara et al., 2017; Sandin et al., 2015). It has an average mass of 74.442 Da, a boiling point 111°C, a density is 1.2 g/mL, It has a specific gravity of 1.2, and surface tension equal to 75 dynes/cm, it is colourless as liquid with a strong odour but When crystalized it stays as $NaOCl.5H_2O$ (Hamano, 1997), actually it is a pentahydrate form which is nonexplosive, yellow or pale green-coloured under refrigerated conditions (Kirihara et al., 2017). It is not combustible but gives out toxic or irritating (fumes /gases) when on fire. According to UN Classification, it is a UN Hazard Class: 8; UN Pack Group: II, III. This chemical is generally stored in Fiberglass Reinforced Plastic (FRP) and also in Rubber Lined Steel tanks with chlorobutyl linings due to the high corrosiveness. Table 1 highlights the important Physical, chemical and hazardous characteristics of Sodium Hypochlorite.

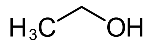
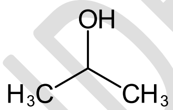
Table No 1: Characteristics of Sodium Hypochlorite

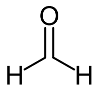
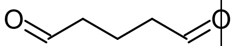
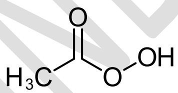
S.No.	Physical Characteristics		References
1.	Colour	Light green to pale yellow	(PubChem, n.d.)
1.	Odour	Chlorine (bleach)	(*The Merck Index Online - Chemicals, Drugs and Biologicals*, n.d.)
2.	pH	Approx 11	(Pradhan et al., 2018)
3.	Melting point:	-5 °C	(*ILO International Chemical Safety Cards (ICSC) - PubChem Data Source*, n.d.)
4.	Boiling point	111 °C	(Aldrich, 1997)
5.	Refractive index	1.3870	www.chemicalbook.com

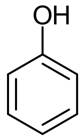
6.	Storage temp	2-8°C	www.chemicalbook.com
7.	Water Solubility	29.3 g/100 g (0 °C)	(*The Merck Index Online - Chemicals, Drugs and Biologicals*, n.d.)
8.	Stability	Highly unstable; hypochlorite ion in aq. sol. is remarkably stable.	(The Merck Index, 1984)
9.	**Chemical Characteristics**		**References**
10.	Trade name	Soda Bleach, Liquid Bleach	(www.chemicalbook.com)
11.	Molecular weight	74.44 g/mol	(https://pubchem.ncbi.nlm.nih.gov)
12.	Incompatible with	Ammonia, amines, organic compounds, and other reducing agents.	(Young, 2002)
13.	**Hazardous Characteristics**		**References**
14.	Symbol (GHS)	 GHS05, GHS09	(https://pubchem.ncbi.nlm.nih.gov)
15.	Overall toxicity	2	(Young, 2002)
16.	Flammability	0	(Young, 2002)
17.	Destructive to skin/eye	2	(Young, 2002)
18.	Self-reactive	No	(Young, 2002)
19.	Hazard Codes	C, Xi, N	(www.chemicalbook.com)
20.	Hazard Class	8	(www.chemicalbook.com)
21.	Packing Group	III	(www.chemicalbook.com)
22.	Hazardous Decomposition Products	Chlorine, oxygen, sodium chlorate.	(www.chemicalbook.com)

Since the outbreak of the COVID-19 pandemic, the world has been concerned about generating increasingly efficient technologies, methods and products at a low cost for sanitizing and disinfecting the environment (surfaces). The distinguishing quality of an efficient disinfectant is remarkable antivirus activity in the lowest contact time (Pradhan et al., 2020). It is reported that more than 5000 tons of disinfectants have been disbursed alone in Wuhan city of China (Zhang et al., 2020). Sanitizing gates have been installed to spray chlorine disinfectants on people at several entry points in Pakistan (thenews.com). Reports from National Poison Data System showed a significant increase in disinfectant poisoning cases after the COVID-19 outbreak. and the largest percentage of poisoning was due to bleach products (62.1 %) followed by non-alcohol disinfectants(36.7%) and hand sanitisers (36.7%) (Chang et al., 2020; Samara et al., 2020). A summary of the various types of disinfectants, their chemical structures, their concentration, and contact time along with their health effects are shown in Table 2.

Table No 2: Comparison of different disinfectants used during COVID-19

S.No.	Categories	Types	Structure	Concentration (%)	Contact time (min)	Hazard class	Health Effects	References
1	Alcohols	Ethanol		78% - 95%	0.5	3	Ethanol as a disinfectant is a highly flammable liquid that causes serious irritation to the eyes and is harmful if swallowed. Prolonged exposure to ethanol can cause damage to vital organs.	(Abdollahi & Hosseini, 2014; Durani & Leaper, 2008; Falagas et al., 2011; Fu et al., 2007; Fukuzaki, 2006; Ge et al., 2008; Kampf, 2018; Kitis, 2004; Zimmerman & Rudis, 2008) ; www.osha.gov (2006)
		Iso-propanol		70% -100%			Isopropanol is a flammable liquid which harms the eyes. Exposure for a longer duration can cause Drowsiness and respiratory irritation.	
2	Chlorine-based	Sodium hypochlorite (liq)		3% - 6%	1- 10	8	Sodium hypochlorite is responsible for causing severe skin burns, eye damage and breathing	

			Na^{+} $Cl{-}O^{-}$				issues.	
		Calcium hypochlorite (solid/powder)	Ca^{2+} $Cl{-}O^{-}$				Calcium hypochlorite is harmful when mistakenly swallowed with severe skin burns and eye damage.	
3	Formaldehyde, Glutaraldehyde	Formaldehyde		0.7% - 1%	2	6	Formaldehyde is an extremely flammable gas which can be fatal on inhalation. Serious eye irritation, allergic skin reactions, breathing problems and future instances of causing cancer.	
		Glutaraldehyde		0.5% - 2.5%			Glutaraldehyde exposure leads to symptoms like difficulty in breathing, and allergic reactions to skin reaction.	
4	Iodine releasing	Povidone-iodine	I—I	0.2% - 7.5%	<1	-	-	
5	Oxidizing agents	Hydrogen peroxide	HO—OH	1% - 3%	1	5	Hydrogen peroxide is a strong oxidizer and an explosive. It can prove h an armful if swallowed, toxic if inhaled and may cause damage to the upper respiratory tract under repeated exposure.	
		Peroxyacetic acid		~0.3%			Peroxyacetic acid is a Flammable liquid. It can prove fatal if inhaled. It is equally harmful to skin, and eyes in the forms of burns and blisters	

6	Phenol based	Phenol		0.5% - 5%	1	6	Phenol can prove harmful to the skin and is toxic after ingestion. It is found to cause genetic defects in individuals and Prolonged exposure can cause damage to the central nervous system, heart, and kidneys	
		Bisphenols						

3. **Impact on Human and Environment**

A quality environment is central to healthy human and animal life. Even the WHO also defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Thus, now environmental health is not only restricted to studying a particular environmental issue or pollutant but is more open to critically analysing the systemic health challenges they pose to humans and other organisms as a whole. It is crucial to understand the relationship between resource-use patterns and the consequential impacts this has on the environment. It enables the creation of policy interventions and safety protocols that a government should introduce and enforce to bring sustainable utilisation of the resources.

The COVID-19 pandemic was a surprise to human survival and a check to the health status of the world community. The widespread information of viral infection and its restriction through the use of sanitisers was advocated as a daily ritual to be practised by all. This, not only forced individuals but also the policymakers to look over disinfectants and cleansers as viable options to prevent and stop the virus as the trials for vaccine of COVID-19 continue to be tested (Al-Sayah, 2020).

In light of this, the chemical sodium hypochlorite has been used unsustainably and extensively in the form of disinfectants and cleansers. The widespread use as a disinfectant and as a cleansing agent in various spaces ranges from households to hospitals. The present-day situation has enabled the disproportionate use of sodium hypochlorite as a solution. The application of sodium hypochlorite under proper quantified concentrations yields effective cleaning results while improper absorptions lead to show effects not only on human beings but also on other biotic and abiotic components of the environment (Abou-Rass & Oglesby, 1981). Thus it becomes important to look for possible interventions, this overutilization of chemicals can cause to human health and the environment. This will act as a precautionary science to look beyond the usual relevance of a cleanser in our day-to-day life. Sodium hypochlorite is no such exemption and thus find its place in the study to evaluate the kinds of health effects it has on human and the environment altogether this will aid the way for proper policy planning and establishing a proper balance between sustainable use and health conditions (Pärt et al., 2013).

3.1 Effect on humans

Sodium hypochlorite is undoubtedly a useful disinfectant. Given the fact of its common use nowadays the other side of the chemical still needs an investigation. Sodium hypochlorite though is useful for sanitization but its repeated exposure to human skin is harmful (McDonnell & Russell, 1999; Racioppi et al., 1994). It is important to wash the affected area immediately with normal water as the alkaline nature of the substance can react with fats and protein present in the tissue resulting in the formation of the soluble protein complex. This reaction is similar to some extent to saponification, which is simply the formation of soaps (Estrela et al., 2002). The soluble protein complexes can permit the hydroxyl ions passage in the direction of going deeper into the skin tissue (Spencer et al., 2007). The possible reason for water application after some time interval will make it difficult to get in contact with the washing liquid. Care must be taken while washing with water, to maintain a low pressure. This is because the eyes can be the sink of the compound formed after sprinkling water on the affected area (Slaughter et al., 2019). Sodium hypochlorite as a disinfectant finds its way into the human system through inhalation and ingestion. Exposure to skin and eyes are the other two means through which sodium hypochlorite causes damage to humans. The probable symptoms of inhalation of sodium hypochlorite causes laboured breathing, burning sensation and sore throat. On the skin, sodium hypochlorite causes skin burning and redness in the form of blisters. Sodium hypochlorite on ingestion causes abdominal pain and without vomiting (Peck et al., 2011). This causes shock, collapse and can cause unconsciousness (Slaughter et al., 2019). It is also responsible for causing burns and redness along with pain on prolonged exposur

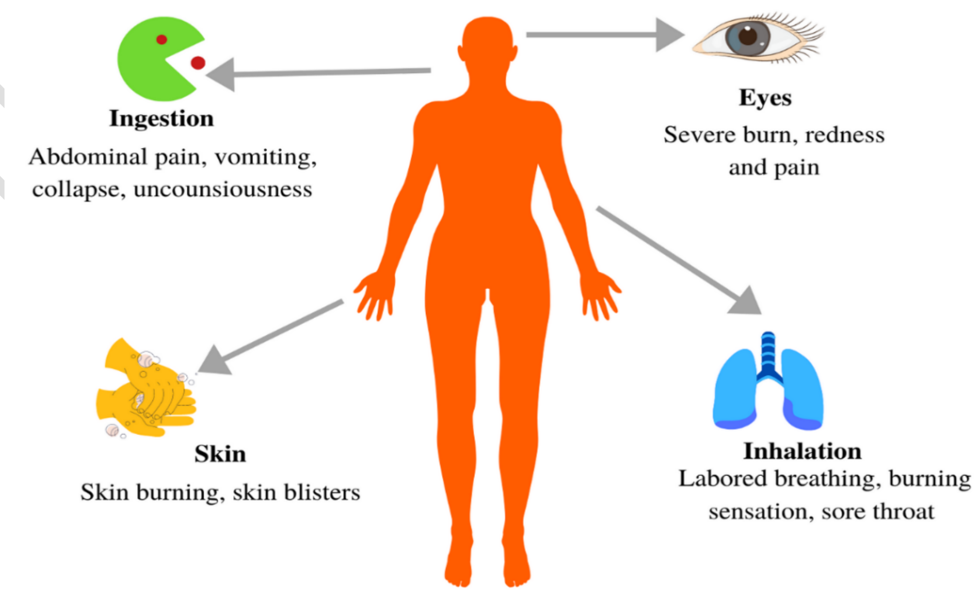


Fig no. 2: Symptoms on various body parts after exposure to sodium hypochlorite

Among many enzymatic activities, pH is a crucial factor. Sodium hypochlorite increases pH. Its basicity is almost above 11. (Estrela et al., 1995) studied the effect of pH change on the enzymatic activities in aerobic bacterial cells and various sites for essential enzymatic processes like cellular division, metabolism, growth, last phase of cell wall formation, oxidative phosphorylation, lipid biosynthesis and transport of electrons in the cytoplasm and they believe that the crucial role of hydroxyl ions is present which are produced from calcium hydroxide are there for showing activity on the cytoplasmic membrane. The alteration in pH gradient is contributed by a high concentration of hydroxyl ions and these act on membrane protein and causes the denaturation of the proteins. The high pH decreases the cytoplasmic integrity thereby injuring it chemically by attacking organic parts or components of the cell (McDonnell & Russell, 1999). Unsaturated fatty acids and phospholipids degradation by peroxidation reaction and which is a saponification type of reaction (Estrela et al., 1995). The cellular metabolism is interfered with by chloramines produced by the chlorination of amino acids. The oxidation directly promotes the irreversible inhibition of enzymes of bacteria in the replacement of hydrogen with chlorine. This inactivation of enzymes has been observed in the irreversible oxidation of sulphydryl groups of cysteine and is a result of the reaction between amino groups and chlorine. Hence sodium hypochlorite possesses antimicrobial properties because of hydroxyl ions and chlorination reaction on the essential sites of bacterial enzymes. Soap and glycerol formation takes place by the degradation of fatty acid and lipids which is the evidence for the dissolution of tissue.

Alternatives like Formaldehyde are often used for surface disinfection and as a fumigant. It is used in decontamination of wood-based surfaces, and the fissures and bricks of mechanical and electronic equipment (de Groot et al., 2009). Formalin can also be used as it is the 37% formaldehyde solution in water. However, glutaraldehyde can also be used to disinfect surfaces. Hydrogen peroxide is another efficient disinfectant. Along with having an oxidizing nature potassium permanganate is utilized as a good disinfectant (Ascenzi, 1996). Hydrogen peroxide, used as foil disinfectant in the food industry preferred over other disinfectants because it has lesser chances of allergic reactions on the skin surface and is thus used as an antiseptic in 3% concentration in solution. Acetic acid and citric acid are mild disinfecting agents. There is a range of chlorine-releasing compounds which are also efficient disinfectants like Sodium and calcium hypochlorite, Hypochlorous acid, Chloramine-T, Monochloramine, Chlorine dioxide, and Trichloroisocyanuric acid. Particularly for these chlorine-related compounds concentration of < 1 ppm of available chlorine is enough to remove viruses, and to kill spores and mycobacteria requiring higher concentrations. Chlorine finds its utility in various spaces, like pathogen deactivation in drinkable water, in swimming pool, wastewater treatment, textile bleaching and for various household purposes (www.lenntech.com).

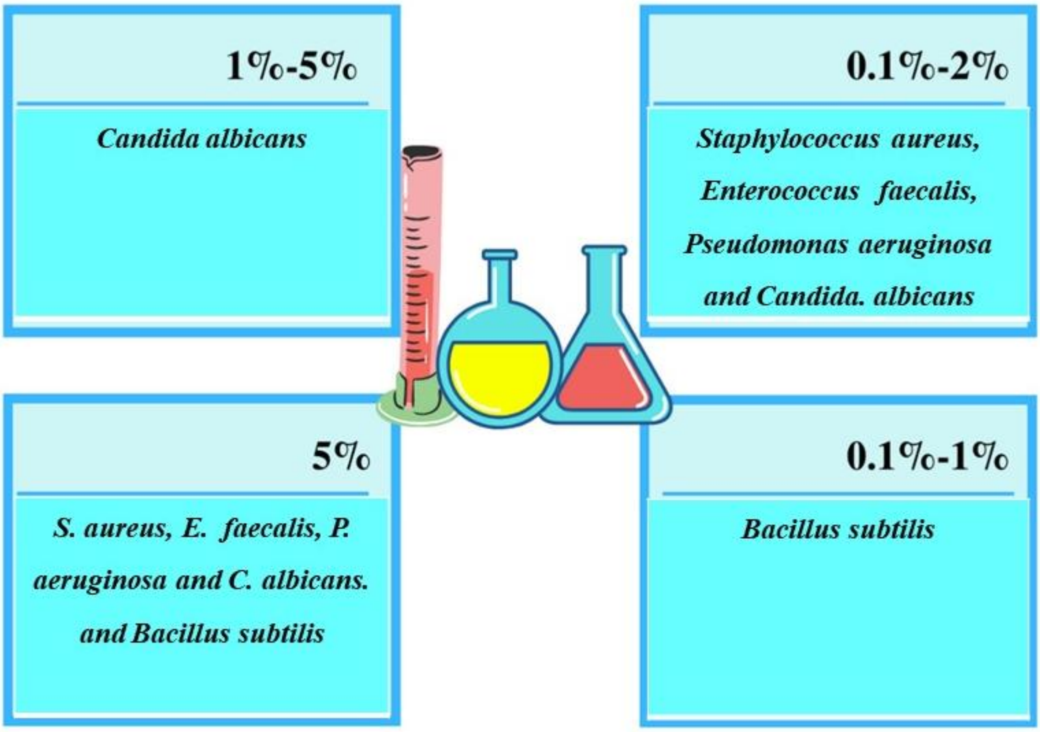


Fig No 3: Representation of effective concentration of Sodium hypochlorite as an antibacterial and antifungal agent (Estrela et al., 2002; Sen et al., 1999)

3.1 Effect of Sodium hypochlorite (NaOCl) in Atmosphere

NaOCl as a disinfectant is being used for several decades. But since the outbreak of the pandemic, its use has amplified unmeasurably. When released into the air, sodium hypochlorite slowly decomposes to form HOCl or hypochlorous acid. Rate of decomposition increases with temperature, concentration, sunlight exposure, and toxicity decreases with age.

$$NaOCl + H_2O \rightarrow HOCl + NaOH \quad (1)$$

At pH 6.5-8.5, half of the active chlorine get dissociated to hypochlorite anion and other half remains as undissociated hypochlorous acid which is volatile but this volatilisation from water to air is very low.The calculated half-life of hypochlorous acid is 114.6 days in the atmosphere but there are an indication of half-life being limited to only few hours (Union, 2012). Moreover, hypochlorite adsorption to aerosol particles and onto soil is very low. Therefore air and atmosphere is not an environmental compartment of concern but inappropriate simultaneous spraying of bleach on a large scale over streets, commercial buildings, markets, shops, roads and railways, residential areas is worrisome. The prime issue is the concentration and amount of hypochlorite solution being used (Zhang et al., 2010).

3.1.1: Effects on the indoor atmosphere

Indoor applications of bleach cleaners lead to the formation of high levels of HOCl and Cl_2 (Wong et al., 2017) where they might react with several unsaturated organic compounds present indoors, due to their high reactivities(Schwartz-Narbonne et al., 2019). Studies conducted by Wong et al., 2017 on the impact of commercial NaOCl solution usage, on indoor air showed significant emissions of particulate chlorine along with HOCl, Cl2O, gaseous Cl2, Chloramines ($NHCl_2$, NCl_3) and the formation and concentration of radicals from HOCl, OH, Cl and ClO is regulated by the indoor lighting. They also reported HOCl and Cl_2 react with α-pinene and limonene in the dark and form gas-phase products which on exposure to indoor lights leads to particle formation. Diffused sunlight and fluorescent light present indoors produce enough energy to initiate HOCl and Cl_2 photolysis forming Cl and OH radicals and particles.

Odabasi, 2008 reported that halogenated volatile organic compounds (VOCs) such as chloroform and carbon tetrachloride present indoors possibly arise from the reaction of HOCl with organic surfactant compounds. Similarly, chloroform was found to be released by the use of bleach in washing machines(Shepherd et al., 1996). Besides, emissions of chloroform from other indoor water activities, such as showering have also been documented (Giardino & Andelman, 1996).

3.1.2: Effects on the outdoor atmosphere

While there have been no reports stating any adverse impact of NaOCl in the atmosphere but concerns arise due to its ability to form chlorinated organic by-product(Falbe, 1987). The type of chlorinated organic formed depends on pH, types of substrates, concentration, temperature and reaction time(Jolley & Carpenter, 1983). As much as 3.8% of the available chlorine in commercial laundering and 2.6% in household laundering had been reported to form chlorinated organic(KRÜSSMANN et al., 1991). Conversion from cleaning kitchen floors, bathroom floors, kitchen counters and toilets was estimated to be 0.5%(Leach, 1980; Smith, 1994). The use of NaOCl in household conditions and those used for paper and pulp bleaching produces different types and the quantity of chlorinated organic by-products. Wood pulp is treated with molecular chlorine at low pH which causes conversion of 10% of chlorine to chlorinated byproducts (Leach, 1980).

KRÜSSMANN et al., 1991reported that bleach solution contain 0.5-21 mg/L of AOX(Adsorbable Organic Halide) composed of chloroform and carbon tetrarchloride. Hypochlorite products that contain surfactants showed 0.5-30mg/kg of chloroform and 1-15 mg/kg of carbon tetrachloride. Concentration of these contaminants was found below occupational exposure limits. Report also estimated that household hypochlorite products worldwide released a maximum of 12 tons of chloroform and 28 tons of carbon tetrachloride during storage in 1992(Cahn, 1994). Carbon tetrachloride causes ozone depletion but the amount that enters the stratosphere (estimated to be 96,000 tons of carbon tetrachloride or 1,508,000 tons of organically bound chlorine) when compared to that from household products contributes from household products negligible (Ballschmiter, 1992).

Cahn (1994) concluded that carbon tetrachloride and chloroform in household hypochlorite products get washed away hence they have no effect on greenhouse gases, acid rain or photochemical smog and are eventually treated at treatment plant. Besides, slow decomposition of NaOCl forms HOCl after being released into air, where photolysis of HOCl takes palce which is a major contributor to the production of tropospheric Cl· radicals

(Chatterjee, 2020; Faxon & Allen, 2013). Chang & Allen, 2006 reported that the addition of hypochlorite solutions in cooling towers and swimming pools and other industrial sources leads to HOCl emission of 10^4 kg day^{-1}. Cl• radicals further reacts with O_3 and form ClO• (reaction 3) or oxidize hydrocarbons (majorly volatile organic compound) forming alkyl radical (reaction 4,5) (Finlayson-Pitts, 1993).

$$HOCl + h\upsilon = Cl\cdot + OH\cdot \quad (2)$$

$$Cl\cdot + O_3 = ClO\cdot + O_2 \quad (3)$$

$$ClO + ClO \rightarrow (Cl_2 + O_2) \text{ or } Cl + Cl + O_2 \quad (4)$$

$$Cl^- + RH(Hydrocarbon) \rightarrow R^{\cdot} + HCl \quad (5)$$

In regions with low NOx conditions, O_3 is destroyed by Cl radicals or the ClO radicals combine to form Cl_2 or regenerate Cl radicals (Simpson et al 2015). The behaviour of Cl radicals towards VOC oxidation is in contrast from that of OH radicals. It was experimentally established that when the concentration of Cl radicals is greater than one order of magnitude than OH radicals, carry equivalent potential to oxidize VOCs (Wingenter et al., 1999).

2.2: Effect of NaOCl in aquatic ecosystem

Sodium hypochlorite (NaOCl) is a chemical compound that is effectively being used for large-scale surface purification of water. Other uses of the chemical include bleaching, removal of odor and disinfection of water. These chemicals enter the aquatic ecosystem through point and non-point sources. Sodium Hypochlorite when reaches the aquatic ecosystem, it reacts with water & this reacts readily with organic, inorganic & biological materials (including proteins and nucleotide bases) to produce a variety of organic chlorinated compounds & most of them are lipophilic, persistent, and toxic in aquatic environments (Estrela et al., 2002; Fajana et al., 2017; Salkinoja-Salonen & Jokela, 1991). The schematic representation of the reaction of Sodium Hypochlorite (NaOCl) in aquatic ecosystem is depicted in fig:1.

Unaltered NaOCl solutions have a pH in the range of 11.5 to 12.5. The caustic compound increases the pH of water when added to it (Jungbluth et al., 2011). Thus, when sodium hypochlorite is added to water, hydrochloric acid is also added simultaneously so that the increase in pH due to hypochlorite could be balanced and the disinfectant ability is enhanced (Souza et al., 2014)

Sodium hypochlorite has been reported to be highly toxic to freshwater organisms, e.g., fishes and invertebrates but with low toxicity to avian and wildlife animals (US EPA 1991). A study revealed that the addition of NaOCl to wastewater can reduce water bacteria pollution and give rise to toxicity effects on aquatic organisms (Emmanuel et al., 2004). According to Raikow et al., 2007 sodium hypochlorite is also toxic to resting eggs of *Artemia* sp. and *Daphnia Mendota*. Similarly in case of Whirligig beetles which are one of the aquatic insects that constitute a major part of the macroinvertebrate diversity of temporary ponds or slow-running water bodies which play an important role in freshwater ecosystems as the adults are ecologically adapted to cleaning off dead invertebrates from the water surface, show significant mortality in the presence of sodium hypochlorite (Fajana et al., 2017). López-Galindo et al., 2010a established that NaClO had lethal effects on *Solea senegalensis* at concentrations of 0.2 mg/L, inducing 100% mortality after 24 h.

The chemical has an impact on the community structure of aquatic ecosystems. At low concentrations it may cause negligible or no damage to aquatic ecosystems but at higher concentrations, it can severely damage the microcosms. In one of the studies, it was found that the influence of the chemical was reversible under the doses of 1.0, 2.5 and 5.0 mg/L, but microcosms could not be restored under the doses of 10.0 mg/L and 20.0 mg/L (Wang et al., 2007).

It can react with the tissues of aquatic organisms and can increase their sensitivity and at higher levels may even be fatal. Thus, at toxic concentrations, sodium hypochlorite has severe and drastic effects on aquatic biodiversity. In a study it has also been seen that the doze of hypochlorite is negatively correlated with productivity (Wang et al., 2007). A study reported that NaOCl inhibits the growth of phytoplankton & also affects the survival of rotifers which are considered to be the first link in the sea food chain thereby causing a detrimental effect on the aquatic ecosystems (López-Galindo et al., 2010b). Chuang et al., 2009 demonstrated that a chlorine concentration of 0.2 mg/L greatly suppressed phytoplankton productivity (photosynthetic capacity). Sodium hypochlorite has adverse effects on coral reefs as well. It causes bleaching of corals and degrades coral reefs (Goffin et al., 1997).

Sodium hypochlorite is highly reactive and can readily degrade and hence does not accumulate. However, it can react with organic compounds in aquatic ecosystems and give rise to organic chlorine compounds which are not only toxic but also persistent in the environment. The effect of sodium hypochlorite is not severe in human compared to aquatic organisms (Fajana et al., 2017).

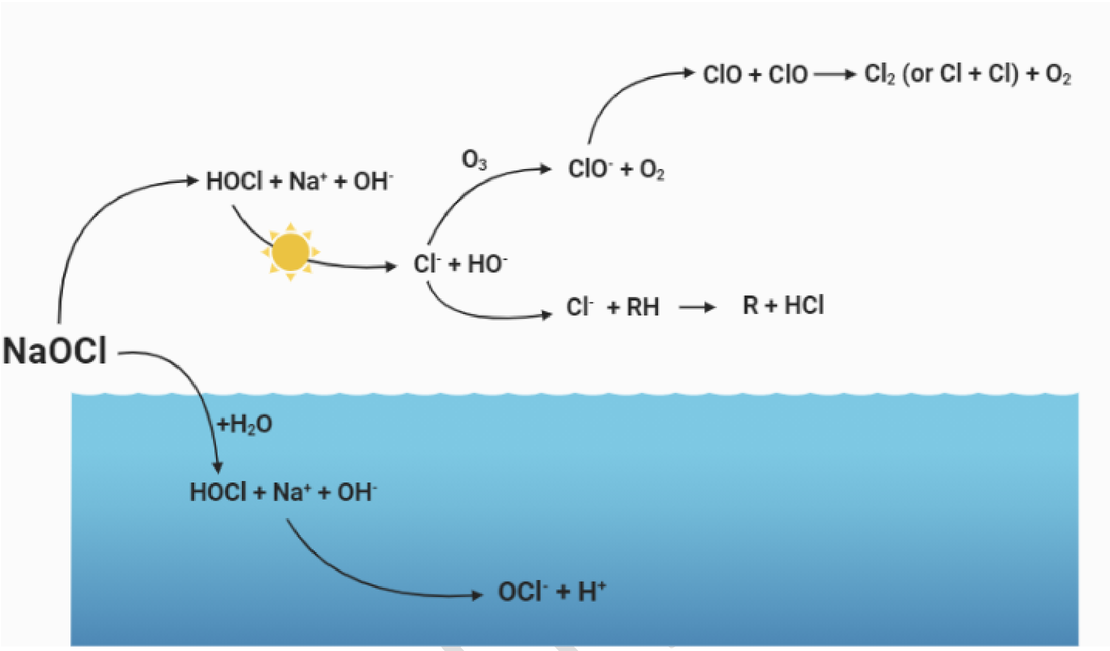


Fig no 4 : Schematic representation of reaction involving Sodium Hypochlorite (NaOCl) in atmosphere & aquatic ecosystem (Emmanuel et al., 2004; Finlayson-Pitts, 1993; Wingenter et al., 1999).

Conclusion

In COVID-19 Pandemic, NaOCl concentration due to the frequency of usages is escalated to a notable extent. This study covers all aspects of the investigation by reviewing the published research papers, review articles, and also commentary, short communications. Although very few publications are available in the public domain. But some industries' websites published important general information about NaOCl's physical and chemical properties. It is discussed that NaOCl is extensively used during the pandemic and continues. Some guidelines are issued for public favor. Mainly NaOCl is used in Hospitals, Institutions, households, and public places as a disinfectant. Apart from disinfectant, it is used like bleaching, detergent and it is considered as an efficient bleaching agent. It is also used for dental treatments. Typically, 1% of NaOCl concentration is used for disinfection purposes. But, According to UN Classification, it is categorized as a UN Hazard Class: 8; UN Pack Group: II, III) mentioned in table no. 1. NaOCl, as a compound, found stable while reacting with an acid, but it releases toxic byproduct i:e Chlorine Gas. Several impacts were noted from various publications like it has a prominent effect on human health. It can easily cause Asthma, Skin irritation due to the high concentration of Chlorine. It is also able to destruct the Mucous membrane, as well as it can cause corrosion of metals. Due to its high corrosiveness, NaOCl is stored in Fiberglass Reinforced Plastic (FRP) and also in Rubber Lined Steel tanks with chlorobutyl linings. Sodium hypochlorite is a common biocidal agent and at 0.21% concentration is effective against Mouse Hepatitis Virus (MHV) Strain MHV-1 with having an exposure time of 30 seconds and having ≥ 4.0 reduction in viral infectivity ($\log_{10}$). It is not entitled to persistent organic pollutant PoPs. Although, when it is exposed to air it gets dissociated into hypochlorous acid and hypochlorite. Generally, its dissociation depends on the temperature. High temperature supports its degradation in the air. So it can be said that those hospitals and institutions, public places are equipped with air conditioners, they may have less decomposition rate of NaOCl. Due to its concentration, visitors to these areas may get affected. It may affect people's skin especially those who have sensitive skin and for all those who have eye issues. NaOCl concentration which is being used arises as the main concern. Recommended concentrations are absent in any policy or any guidelines by local regulatory authorities. Chloroform can be resulted after using bleaching in washing machines. In water, Every chemical compound has effects on aquatic animals for obvious. But it highly depends on the concentration, lifetime of the pollutant. NaOCl interacts with all components like organic, inorganic, biological components of the aquatic ecosystem. the interaction with different components results in organic chlorinated compounds where most of which are lipophilic, toxicants, and persistent in the aquatic environment.

Some major finding from the available literature

- NaOCl is highly toxic to freshwater organisms like fishes and invertebrates.(US EPA 1991)
- NaOCl is low toxic to birds and Wildlife animals.
- NaOCl has a negative correlation with productivity. (Wang et. al. 2007)
- NaOCl inhibits phytoplankton growth. (López-Galindo et. al. (2010b) & Chuang et al. (2009))
- NaOCl shows notable adverse effect on Coral reef. It is a bleaching agent too. (Goffin et. al. 1997)

NaoCl has shown its hostile behaviour in the environment and shows a prominent effect in Air, Water, and on the human being as well. But it also easily degradable, has less life in environmental components. It also does not show Bioaccumulation and biomagnification properties as that is not mentioned in any research paper.

References:

Abdollahi, M., & Hosseini, A. (2014). Formaldehyde. *Encyclopedia of Toxicology*. https://doi.org/10.1016/B978-0-12-386454-3.00388-2

Abou-Rass, M., & Oglesby, S. W. (1981). The effects of temperature, concentration, and tissue type on the solvent ability of sodium hypochlorite. *Journal of Endodontics*, *7*(8), 376–377. https://doi.org/10.1016/S0099-2399(81)80059-3

Abou-Rass, Marwan, & Oglesby, S. W. (1981). The effects of temperature, concentration, and tissue type on the solvent ability of sodium hypochlorite. *Journal of Endodontics*, *7*(8), 376–377. https://doi.org/10.1016/S0099-2399(81)80059-3

Aldrich Chemical Company. *Aldrich catalog handbook of fine chemicals, 1996-1997*. Aldrich Chemical Co.

Andrade, F. P. de, & Pereira, C. de B. (2020). Use of chlorine solutions as disinfectant agents in health units to contain the spread of COVID-19. *Journal of Health & Biological Sciences*, *8*(1), 1–9. https://doi.org/10.12662/2317-3076jhbs.v8i1.3256.p1-9.2020

Ascenzi, J. M. (1996). *Handbook of disinfectants and antiseptics*. M. Dekker.

Ballschmiter, K. (1992). Transport and Fate of Organic Compounds in the Global Environment. *Angewandte Chemie International Edition in English*, *31*(5), 487–515. https://doi.org/10.1002/anie.199204873

Boone, S. A., & Gerba, C. P. (2007). Significance of Fomites in the Spread of Respiratory and Enteric Viral Disease. *Applied and Environmental Microbiology*, *73*(6), 1687–1696. https://doi.org/10.1128/AEM.02051-06

Brankston, G., Gitterman, L., Hirji, Z., Lemieux, C., & Gardam, M. (2007). Transmission of influenza A in human beings. *The Lancet. Infectious Diseases*, *7*(4), 257–265. https://doi.org/10.1016/S1473-3099(07)70029-4

Cahn, A. (1994). *Proceedings of the 3rd World Conference on Detergents: Global Perspectives*. The American Oil Chemists Society.

Chang, A., Schnall, A. H., Law, R., Bronstein, A. C., Marraffa, J. M., Spiller, H. A., Hays, H. L., Funk, A. R., Mercurio-Zappala, M., Calello, D. P., Aleguas, A., Borys, D. J., Boehmer, T., & Svendsen, E. (2020). Cleaning and Disinfectant Chemical Exposures and Temporal Associations with COVID-19—National Poison Data System, United States, January 1, 2020–March 31, 2020. *Morbidity and Mortality Weekly Report*, *69*(16), 496–498. https://doi.org/10.15585/mmwr.mm6916e1

Chang, S., & Allen, D. T. (2006). Atmospheric Chlorine Chemistry in Southeast Texas: Impacts on Ozone Formation and Control. *Environmental Science & Technology*, *40*(1), 251–262. https://doi.org/10.1021/es050787z

Chatterjee, A. (2020). Use of Hypochlorite Solution as Disinfectant during COVID-19 Outbreak in India: From the Perspective of Human Health and Atmospheric Chemistry. *Aerosol and Air Quality Research*, *20*(7), 1516–1519. https://doi.org/10.4209/aaqr.2020.05.0253

Chauret, C., Volk, C., Stover, L., Dykstra, T., Andrews, R., & Gagnon, G. (2005). Effect of disinfectants on microbial ecology in model distribution systems. *Journal of Water and Health*, *3*, 359–369. https://doi.org/10.2166/wh.2005.050

Chlorine as disinfectant for water. (n.d.). Retrieved October 21, 2020, from https://www.lenntech.com/processes/disinfection/chemical/disinfectants-chlorine.htm

Chuang, Y.-L., Yang, H.-H., & Lin, H.-J. (2009). Effects of a thermal discharge from a nuclear power plant on phytoplankton and periphyton in subtropical coastal waters. *Journal of Sea Research*, *61*(4), 197–205. https://doi.org/10.1016/j.seares.2009.01.001

Cleaning and disinfection of environmental surfaces in the context of COVID-19. (n.d.). Retrieved October 22, 2020, from https://www.who.int/publications-detail-redirect/cleaning-and-disinfection-of-environmental-surfaces-inthe-context-of-covid-19

de Groot, A. C., Flyvholm, M.-A., Lensen, G., Menné, T., & Coenraads, P.-J. (2009). Formaldehyde-releasers: Relationship to formaldehyde contact allergy. Contact allergy to formaldehyde and inventory of formaldehyde-releasers. *Contact Dermatitis*, *61*(2), 63–85. https://doi.org/10.1111/j.1600-0536.2009.01582.x

Dellanno, C., Vega, Q., & Boesenberg, D. (2009). The antiviral action of common household disinfectants and antiseptics against murine hepatitis virus, a potential surrogate for SARS coronavirus. *American Journal of Infection Control*, *37*(8), 649–652. https://doi.org/10.1016/j.ajic.2009.03.012

Document Display | NEPIS | US EPA. (n.d.). Retrieved October 22, 2020, from https://nepis.epa.gov/Exe/ZyNET.exe/901A0700.txt?ZyActionD=ZyDocument&Client=EPA&Index=1981%20Thru%201985&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C81THRU85%5CTXT%5C00000014%5C901A0700.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C&MaximumDocuments=1&FuzzyDegree=0&ImageQuality

=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=2#

Durani, P., & Leaper, D. (2008). Povidone-iodine: Use in hand disinfection, skin preparation and antiseptic irrigation. *International Wound Journal*, *5*(3), 376–387. https://doi.org/10.1111/j.1742-481X.2007.00405.x

Emmanuel, E., Keck, G., Blanchard, J.-M., Vermande, P., & Perrodin, Y. (2004). Toxicological effects of disinfections using sodium hypochlorite on aquatic organisms and its contribution to AOX formation in hospital wastewater. *Environment International*, *30*(7), 891–900. https://doi.org/10.1016/j.envint.2004.02.004

Estrela, C., Sydney, G. B., Bammann, L. L., & Felippe Júnior, O. (1995). Mechanism of action of calcium and hydroxyl ions of calcium hydroxide on tissue and bacteria. *Brazilian Dental Journal*, *6*(2), 85–90.

Estrela, Carlos, Estrela, C. R. A., Barbin, E. L., Spanó, J. C. E., Marchesan, M. A., & Pécora, J. D. (2002). Mechanism of action of sodium hypochlorite. *Brazilian Dental Journal*, *13*(2), 113–117. https://doi.org/10.1590/S0103-64402002000200007

Fajana, H. O., Amusan, B. O., Koleosho, A., & Owojori, O. J. (2017). Acute toxicity of a household bleach, sodium hypochlorite, to a whirligig beetle Orectogyrus alluaudi Régimbart, 1889 (Coleoptera: Gyrinidae). *Aquatic Insects*, *38*(1–2), 93–100. https://doi.org/10.1080/01650424.2017.1326614

Falagas, M. E., Thomaidis, P. C., Kotsantis, I. K., Sgouros, K., Samonis, G., & Karageorgopoulos, D. E. (2011). Airborne hydrogen peroxide for disinfection of the hospital environment and infection control: A systematic review. *Journal of Hospital Infection*, *78*(3), 171–177. https://doi.org/10.1016/j.jhin.2010.12.006

Falbe, J. (Ed.). (1987). *Surfactants in Consumer Products: Theory, Technology and Application*. Springer-Verlag. https://doi.org/10.1007/978-3-642-71545-7

Fathizadeh, H., Maroufi, P., Momen-Heravi, M., Dao, S., Köse, Ş., Ganbarov, K., Pagliano, P., Esposito, S., & Kafil, H. S. (2020). Protection and disinfection policies against SARS-CoV-2 (COVID-19). *Le Infezioni in Medicina*, *28*(2), 185–191.

Faxon, C. B., & Allen, D. T. (2013). Chlorine chemistry in urban atmospheres: A review. *Environmental Chemistry*, *10*(3), 221–233. https://doi.org/10.1071/EN13026

Finlayson-Pitts, B. J. (1993). Chlorine atoms as a potential tropospheric oxidant in the marine boundary layer. *Research on Chemical Intermediates*, *19*(3), 235–249. https://doi.org/10.1163/156856793X00091

Fu, E., McCue, K., & Boesenberg, D. (2007). Chemical Disinfection of Hard Surfaces-Household, Industrial and Institutional Settings. *Handbook for Cleaning/Decontamination of Surfaces*, *1*, 573–592. https://doi.org/10.1016/B978-044451664-0/50017-6

Fukuzaki, S. (2006). Mechanisms of Actions of Sodium Hypochlorite in Cleaning and Disinfection Processes. *Biocontrol Science*, *11*(4), 147–157. https://doi.org/10.4265/bio.11.147

Ge, F., Zhu, L., & Wang, J. (2008). Distribution of chlorination products of phenols under various pHs in water disinfection. *Desalination*, *225*, 156–166. https://doi.org/10.1016/j.desal.2007.03.016

Giardino, N. J., & Andelman, J. B. (1996). Characterization of the emissions of trichloroethylene, chloroform, and 1,2-dibromo-3-chloropropane in a full-size, experimental shower. *Journal of Exposure Analysis and Environmental Epidemiology*, *6*(4), 413–423.

Goffin, V., Piérard, G. E., Henry, F., Letawe, C., & Maibach, H. I. (1997). Sodium Hypochlorite, Bleaching Agents, and the Stratum Corneum. *Ecotoxicology and Environmental Safety*, *37*(3), 199–202. https://doi.org/10.1006/eesa.1997.1537

Hamano, A. (1997). The formation and decomposition of sodium hypochlorite anhydrous salt and its pentahydrate. *Kayaku Gakkaishi*, *58*(4), 152–156.

Health, A. G. D. of. (2020, May 19). *Quarantine for coronavirus (COVID-19)* [Text]. Australian Government Department of Health; Australian Government Department of Health. https://www.health.gov.au/news/health-alerts/novel-coronavirus-2019-ncov-health-alert/how-to-protect-yourself-and-others-from-coronavirus-covid-19/quarantine-for-coronavirus-covid-19

Hulkower, R. L., Casanova, L. M., Rutala, W. A., Weber, D. J., & Sobsey, M. D. (2011). Inactivation of surrogate coronaviruses on hard surfaces by health care germicides. *American Journal of Infection Control*, *39*(5), 401–407. https://doi.org/10.1016/j.ajic.2010.08.011

ILO International Chemical Safety Cards (ICSC)—PubChem Data Source. (n.d.). Retrieved October 21, 2020, from https://pubchem.ncbi.nlm.nih.gov/source/ILO%20International%20Chemical%20Safety%20Cards%20(ICSC)

Jayaweera, M., Perera, H., Gunawardana, B., & Manatunge, J. (2020). Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. *Environmental Research*, *188*, 109819. https://doi.org/10.1016/j.envres.2020.109819

Jolley, R. L., & Carpenter, J. H. (1983). Review of the chemistry and environmental fate of reactive oxidant species in chlorinated water. *Water Chlorination: Environmental Impact and Health Effects*, *4*.

Jungbluth, H., Marending, M., De-Deus, G., Sener, B., & Zehnder, M. (2011). Stabilizing Sodium Hypochlorite at High pH: Effects on Soft Tissue and Dentin. *Journal of Endodontics*, *37*(5), 693–696. https://doi.org/10.1016/j.joen.2011.02.019

Kampf, G. (2018). Efficacy of ethanol against viruses in hand disinfection. *The Journal of Hospital Infection*, *98*(4), 331–338. https://doi.org/10.1016/j.jhin.2017.08.025

Kaufman, A. Y., & Keila, S. (1989). Hypersensitivity to sodium hypochlorite. *Journal of Endodontics*, *15*(5), 224–226. https://doi.org/10.1016/S0099-2399(89)80241-9

Kirihara, M., Okada, T., Sugiyama, Y., Akiyoshi, M., Matsunaga, T., & Kimura, Y. (2017). Sodium Hypochlorite Pentahydrate Crystals (NaOCl·5H2O): A Convenient and Environmentally Benign Oxidant for Organic Synthesis. *Organic Process Research & Development*, *21*(12), 1925–1937. https://doi.org/10.1021/acs.oprd.7b00288

Kitis, M. (2004). Disinfection of wastewater with peracetic acid: A review. *Environment International*, *30*(1), 47–55. https://doi.org/10.1016/S0160-4120(03)00147-8

KRÜSSMANN, H., HLOCH, H.-G., BOHNEN, J., & KNOFE, G. (1991). Gewerbliche Textilreinigung: Stand der Technik und Entwicklungen, Forderungen an die Reinigungschemie. *Gewerbliche Textilreinigung : Stand Der Technik Und Entwicklungen, Forderungen an Die Reinigungschemie*, *28*(6), 487–492.

Lages, S. L. S., Ramakrishnan, M. A., & Goyal, S. M. (2008). In-vivo efficacy of hand sanitisers against feline calicivirus: A surrogate for norovirus. *Journal of Hospital Infection*, *68*(2), 159–163. https://doi.org/10.1016/j.jhin.2007.11.018

Leach, J. M. (1980). Loadings and effects of chlorinated organics from bleached pulp mills. *Water Chlorination: Environmental Impact and Health Effects*, *3*, 325–334.

López-Galindo, C., Garrido, M. C., Casanueva, J. F., & Nebot, E. (2010). Degradation models and ecotoxicity in marine waters of two antifouling compounds: Sodium hypochlorite and an alkylamine surfactant. *Science of the Total Environment*, *408*(8), 1779–1785.

López-Galindo, C., Vargas-Chacoff, L., Nebot, E., Casanueva, J. F., Rubio, D., Solé, M., & Mancera, J. M. (2010). Biomarker responses in Solea senegalensis exposed to sodium hypochlorite used as antifouling. *Chemosphere*, *78*(7), 885–893. https://doi.org/10.1016/j.chemosphere.2009.11.022

McDonnell, G., & Russell, A. D. (1999). Antiseptics and Disinfectants: Activity, Action, and Resistance. *Clinical Microbiology Reviews*, *12*(1), 147–179. https://doi.org/10.1128/CMR.12.1.147

Mh, A.-S. (2020). Chemical disinfectants of COVID-19: An overview. *Journal of Water and Health*, *18*(5), 843–848. https://doi.org/10.2166/wh.2020.108

Odabasi, M. (2008). Halogenated Volatile Organic Compounds from the Use of Chlorine-Bleach-Containing Household Products. *Environmental Science & Technology*, *42*(5), 1445–1451. https://doi.org/10.1021/es702355u

Pärt, P., Jarosinska, D., & Hoogeveen, Y. (2013). *Environment and human health*.

Peck, B., Workeneh, B., Kadikoy, H., Patel, S. J., & Abdellatif, A. (2011). Spectrum of sodium hypochlorite toxicity in man—Also a concern for nephrologists. *NDT Plus*, *4*(4), 231–235. https://doi.org/10.1093/ndtplus/sfr053

Pickering, A., Davis, J., & Boehm, A. (2011). Efficacy of alcohol-based hand sanitizer on hands soiled with dirt and cooking oil. *Journal of Water and Health*, *9*, 429–433. https://doi.org/10.2166/wh.2011.138

Pradhan, D., Biswasroy, P., Kumar Naik, P., Ghosh, G., & Rath, G. (2020). A Review of Current Interventions for COVID-19 Prevention. *Archives of Medical Research*, *51*(5), 363–374. https://doi.org/10.1016/j.arcmed.2020.04.020

Pradhan, M. S., Gunwal, M., Shenoi, P., Sonarkar, S., Bhattacharya, S., & Badole, G. (2018). Evaluation of pH and Chlorine Content of a Novel Herbal Sodium Hypochlorite for Root Canal Disinfection: An Experimental In vitro Study. *Contemporary Clinical Dentistry*, *9*(Suppl 1), S74–S78. https://doi.org/10.4103/ccd.ccd_60_18

Pratelli, A. (2008). Canine coronavirus inactivation with physical and chemical agents. *Veterinary Journal (London, England : 1997)*, *177*(1), 71–79. https://doi.org/10.1016/j.tvjl.2007.03.019

PubChem. (n.d.). *Sodium hypochlorite*. Retrieved October 21, 2020, from https://pubchem.ncbi.nlm.nih.gov/compound/23665760

Racioppi, F., Daskaleros, P. A., Besbelli, N., Borges, A., Deraemaeker, C., Magalini, S. I., Martinez Arrifta, R., Pulce, C., Ruggerone, M. L., & Vlachos, P. (1994). Household bleaches based on sodium hypochlorite: Review of acute toxicology and poison control center experience. *Food and Chemical Toxicology*, *32*(9), 845–861. https://doi.org/10.1016/0278-6915(94)90162-7

Raikow, D. F., Landrum, P. F., & Reid, D. F. (2007). Aquatic invertebrate resting egg sensitivity to glutaraldehyde and sodium hypochlorite. *Environmental Toxicology and Chemistry*, *26*(8), 1770–1773. https://doi.org/10.1897/06-582R.1

Salkinoja-Salonen, M. S., & Jokela, J. K. (1991). Measurement of organic halogen compounds in urine as an indicator of exposure. *Scandinavian Journal of Work, Environment & Health*, *17*(1), 75–78.

Samara, F., Badran, R., & Dalibalta, S. (2020). Are Disinfectants for the Prevention and Control of COVID-19 Safe? *Health Security*. https://doi.org/10.1089/hs.2020.0104

Sandin, S., Karlsson, R. K. B., & Cornell, A. (2015). Catalyzed and Uncatalyzed Decomposition of Hypochlorite in Dilute Solutions. *Industrial & Engineering Chemistry Research*, *54*(15), 3767–3774. https://doi.org/10.1021/ie504890a

Sattar, S. A., Springthorpe, V. S., Karim, Y., & Loro, P. (1989). Chemical disinfection of non-porous inanimate surfaces experimentally contaminated with four human pathogenic viruses. *Epidemiology and Infection*, *102*(3), 493–505. https://doi.org/10.1017/s0950268800030211

Schwartz-Narbonne, H., Wang, C., Zhou, S., Abbatt, J. P. D., & Faust, J. (2019). Heterogeneous Chlorination of Squalene and Oleic Acid. *Environmental Science & Technology*, *53*(3), 1217–1224. https://doi.org/10.1021/acs.est.8b04248

Shepherd, J. L., Corsi, R. L., & Kemp, J. (1996). Chloroform in Indoor Air and Wastewater: The Role of Residential Washing Machines. *Journal of the Air & Waste Management Association (1995)*, *46*(7), 631–642. https://doi.org/10.1080/10473289.1996.10467497

Slaughter, R. J., Watts, M., Vale, J. A., Grieve, J. R., & Schep, L. J. (2019a). The clinical toxicology of sodium hypochlorite. *Clinical Toxicology (Philadelphia, Pa.)*, *57*(5), 303–311. https://doi.org/10.1080/15563650.2018.1543889

Slaughter, R. J., Watts, M., Vale, J. A., Grieve, J. R., & Schep, L. J. (2019b). The clinical toxicology of sodium hypochlorite. *Clinical Toxicology (Philadelphia, Pa.)*, *57*(5), 303–311. https://doi.org/10.1080/15563650.2018.1543889

Smith, W. L. (1994). Human and environmental safety of hypochlorite. *Proceedings of the Third World Conference and Exhibition on Detergents: Global Perspectives. AOCS Press, Champaign, Ill*, 183–192.

Sodium hypochlorite CAS#: 7681-52-9. (n.d.). Retrieved October 21, 2020, from https://www.chemicalbook.com/ProductChemicalPropertiesCB1705333_EN.htm

Souza, E. M., Calixto, A. M., Lima, C. N. e, Pappen, F. G., & De-Deus, G. (2014). Similar Influence of Stabilized Alkaline and Neutral Sodium Hypochlorite Solutions on the Fracture Resistance of Root Canal–treated Bovine Teeth. *Journal of Endodontics*, *40*(10), 1600–1603. https://doi.org/10.1016/j.joen.2014.02.028

Spencer, H. R., Ike, V., & Brennan, P. A. (2007). Review: The use of sodium hypochlorite in endodontics — potential complications and their management. *British Dental Journal*, *202*(9), 555–559. https://doi.org/10.1038/bdj.2007.374

Tamimi, A., Carlino, S., Edmonds, S., & Gerba, C. (2014). Impact of an Alcohol-Based Hand Sanitizer Intervention on the Spread of Viruses in Homes. *Food and Environmental Virology*, *6*. https://doi.org/10.1007/s12560-014-9141-9

Tellier, R. (2006). Review of Aerosol Transmission of Influenza A Virus. *Emerging Infectious Diseases*, *12*(11), 1657–1662. https://doi.org/10.3201/eid1211.060426

Tennant, B. J., Gaskell, R. M., & Gaskell, C. J. (1994). Studies on the survival of canine coronavirus under different environmental conditions. *Veterinary Microbiology*, *42*(2), 255–259. https://doi.org/10.1016/0378-1135(94)90024-8

The merck index, 10th Ed. Edited By Martha Windholz. Merck & Co., P.O. Box 2000, Rahway, NJ 07065. 1983. 2052 pp. 18 × 25.5 cm. Price $28.50. (1984). *Journal of Pharmaceutical Sciences*, *73*(6), 862–862. https://doi.org/10.1002/jps.2600730651

The Merck Index Online—Chemicals, drugs and biologicals. (n.d.). Retrieved October 21, 2020, from https://www.rsc.org/merck-index

Tyan, K., Kang, J., Jin, K., & Kyle, A. M. (2018). Evaluation of the antimicrobial efficacy and skin safety of a novel color additive in combination with chlorine disinfectants. *American Journal of Infection Control*, *46*(11), 1254–1261. https://doi.org/10.1016/j.ajic.2018.04.223

Union, E. (2012). Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products. *Off J Eur Union L*, *167*, 1–116.

Walkthrough gates developed to check coronavirus spread. (n.d.). Retrieved October 24, 2020, from https://www.thenews.com.pk/print/639732-walkthrough-gates-developed-to-check-coronavirus-spread

Wang, J., & Du, G. (2020). COVID-19 may transmit through aerosol. *Irish Journal of Medical Science (1971 -)*, *189*(4), 1143–1144. https://doi.org/10.1007/s11845-020-02218-2

Wang, Y., Wang, L., & Lu, Y. (2007). Effects of sodium hypochlorite on structure and function of pond microcosms. *Wei Sheng Yan Jiu= Journal of Hygiene Research*, *36*(2), 144–147.

WHO Director-General's opening remarks at the media briefing on COVID-19—11 March 2020. (n.d.). Retrieved October 20, 2020, from https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020

Wingenter, O. W., Blake, D. R., Blake, N. J., Sive, B. C., Rowland, F. S., Atlas, E., & Flocke, F. (1999). Tropospheric hydroxyl and atomic chlorine concentrations, and mixing timescales determined from hydrocarbon and halocarbon measurements made over the Southern Ocean. *Journal of Geophysical Research: Atmospheres*, *104*(D17), 21819–21828. https://doi.org/10.1029/1999JD900203

Wong, J. P. S., Carslaw, N., Zhao, R., Zhou, S., & Abbatt, J. P. D. (2017). Observations and impacts of bleach washing on indoor chlorine chemistry. *Indoor Air*, *27*(6), 1082–1090. https://doi.org/10.1111/ina.12402

Yelin, D., Wirtheim, E., Vetter, P., Kalil, A. C., Bruchfeld, J., Runold, M., Guaraldi, G., Mussini, C., Gudiol, C., Pujol, M., Bandera, A., Scudeller, L., Paul, M., Kaiser, L., & Leibovici, L. (2020). Long-term consequences of COVID-19: Research needs. *The Lancet. Infectious Diseases*, *20*(10), 1115–1117. https://doi.org/10.1016/S1473-3099(20)30701-5

Young, J. A. (2002). Sodium Hypochlorite Solution. *Journal of Chemical Education*, *79*(10), 1196. https://doi.org/10.1021/ed079p1196

Zhang, H., Tang, W., Chen, Y., & Yin, W. (2020). Disinfection threatens aquatic ecosystems. *Science*, *368*(6487), 146–147. https://doi.org/10.1126/science.abb8905

Zhang, K., Kim, Y. K., Cadenaro, M., Bryan, T. E., Sidow, S. J., Loushine, R. J., Ling, J., Pashley, D. H., & Tay, F. R. (2010). Effects of different exposure times and concentrations of sodium hypochlorite/ethylenediaminetetraacetic acid on the structural integrity of mineralized dentin. *Journal of Endodontics*, *36*(1), 105–109. https://doi.org/10.1016/j.joen.2009.10.020

Zimmerman, J. L., & Rudis, M. (2008). Poisonings. *Critical Care Medicine: Principles of Diagnosis and Management in the Adult*, 1453–1474. https://doi.org/10.1016/B978-032304841-5.50071-6