NaDCC Disinfectant in Janitorial Cleaning and Comparison to Bleach: Exposure Assessment

TURI
TOXICS USE REDUCTION INSTITUTE
UMASS LOWELL

TURI Report #2021-001
April 2021

Acknowledgments

This report was prepared by staff from the Toxics Use Reduction Institute and the University of Massachusetts Lowell. Pia Markkanen surveyed the literature and designed and conducted laboratory experiments. Joy Onasch, Michael Ellenbecker, and Elizabeth Harriman contributed technical expertise.

TURI
TOXICS USE REDUCTION INSTITUTE
UMASS LOWELL

Toxics Use Reduction Institute
University of Massachusetts Lowell
The Offices at Boott Mills West
126 John St., Suite 14 (2nd floor)
Lowell, MA 01852-1152
(978) 934-3275 • www.turi.org

Contents

(this page intentionally left blank)

I. Introduction

Strong cleaning and disinfecting (C&D) products such as those containing bleach and quaternary ammonium compounds (quats) are increasingly used as microbicides for infection prevention and sanitation of environmental surfaces in various settings, including health care, child care, school, food service and production facilities, dairies and breweries, and many other industrial facilities. C&D is an important infection prevention and sanitation strategy as various microorganisms can be dangerous to immunocompromised and other vulnerable populations. However, the trade-off is that the respiratory health of workers and the general public can be impacted. There is increasing scientific evidence that C&D is associated with respiratory illness, including asthma.[1] The Association of Occupational and Environmental Clinics designates both sodium hypochlorite (the active ingredient in bleach) and benzalkonium chloride (a commonly-used quat) as sensitizer-induced asthmagens.[2,3]

The human health and environmental concerns of strong C&D products call for less harmful, yet effective, alternatives. Some have proposed that sodium dichloroisocyanurate (NaDCC) disinfection tablets meet those criteria, and thus should be considered as a preferred alternative to bleach.

II. Objective

The objective of this report is to summarize the safety, health, and environmental characteristics of the NaDCC cleaning product and how it compares to bleach-containing products in terms of C&D effectiveness, safety, health, and environmental protection. In the Background section, the report describes the composition of NaDCC tablets, their strengths and limitations compared to bleach, and key literature findings related to NaDCC and bleach. Next, the report describes the methods and key findings of a 2019 TURI laboratory investigation to assess airborne chlorine exposures generated by disinfectant solutions prepared from NaDCC tablets and bleach. At the end, the report suggests what the findings of the lab experiments may signify from the prevention point of view.

III. Background Information from Literature

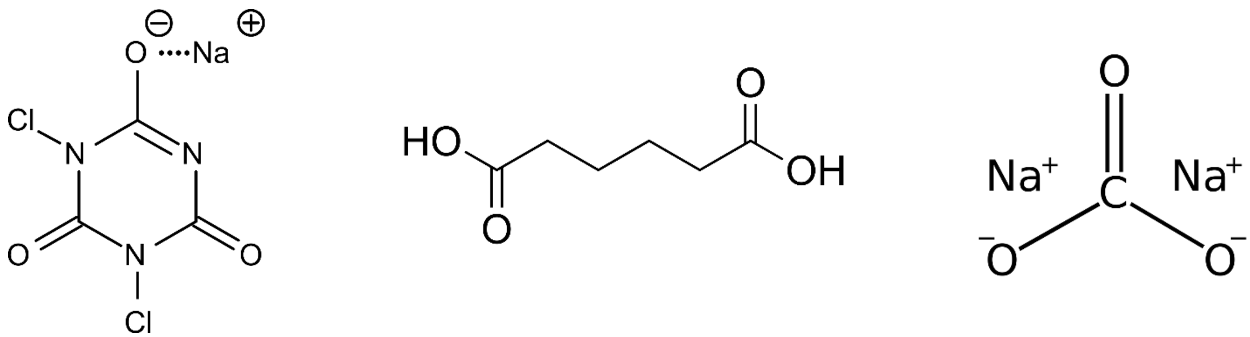
What are NaDCC tablets?

The active ingredient in the NaDCC tablet is sodium dichloroisocyanurate (CAS: 2893-78-9). It is often abbreviated as NaDCC and has several other synonyms. For example, the European Chemicals Agency (ECHA) uses the synonym troclosene sodium.[4] For consistency, this report uses NaDCC.

NaDCC is effective in killing microorganisms. Tablets are dissolved in water to prepare a disinfecting solution for hard, non-porous environmental surfaces. It is used as a disinfectant in various settings, such as in the treatment of water, environmental surfaces in healthcare, medical equipment, and a wide range of applications in other industrial settings.[4-7] The U.S. Environmental Protection Agency has approved the use of NaDCC as a hard-surface disinfectant for hospitals and manufacturing facilities when used in accordance with the label.[8]

In addition to the disinfectant NaDCC (45- 50%), the product Safety Data Sheet for the BruTab6S NaDCC tablet indicates two other ingredients: adipic acid (an aliphatic carboxylic acid, 35-40%) and sodium carbonate (an alkali metal, 10-15%).[9]

An international patent approved for a similar NaDCC disinfection tablet describes that adipic acid and sodium carbonate provide an effervescent base in which the disinfectant NaDCC blends.[10] The aliphatic carboxylic acid (adipic acid) reacts with an alkali metal carbonate (sodium carbonate) forming carbon dioxide bubbles, thereby facilitating the effervescent disintegration of the tablet in water. Adipic acid is non-hygroscopic (i.e., does not absorb moisture), which helps to preserve the product stability; when a tablet is added into water, adipic acid slows the effervescent reaction so that most chlorine dissolves into the solution effectively.[10]



Figures 1, 2, and 3. Molecular structures for the three ingredients in BruTab6S tablets. NaDCC (left) is the active disinfectant ingredient. Adipic acid (middle) and sodium carbonate (right) provide an effervescent base to dissolve the disinfectant in water.[10]

How does NaDCC compare to bleach?

Many water-based disinfectants rely on the release of free available chlorine (FAC) in solution as the antimicrobial agent. "The microbicidal activity of chlorine is attributed largely to undissociated hypochlorous acid (HOCl). The dissociation of HOCI to the less microbicidal form (hypochlorite ion OCl-) depends on pH. The disinfecting efficacy of chlorine decreases with an increase in pH that parallels the conversion of undissociated HOCI to OCl-."[11] Other background references provide additional information.[7,12,13]

NaDCC is a stable source of hypochlorous acid when dissolved in water, as follows:[6,7]

$NaCl_2(NCO)_3$	+	2 H_2O	⇌	2 HOCl	+	$NaH_2(NCO)_3$
NaDCC		*water*		*hypochlorous acid*		*sodium cyanurate*

The active ingredient in bleach, sodium hypochlorite, also generates FAC in solution in the form of undissociated HOCl and the OCl- ion:[7]

NaOCl	+	H_2O	⇌	HOCl	+	NaOH
sodium hypochlorite (bleach)		*water*		*hypochlorous acid*		*sodium hydroxide*

HOCl	⇌	OCl-	+	H+
hypochlorous acid		*hypochlorite ion*		*hydrogen ion*

One difference between the two products is that bleach releases all of its chlorine as FAC immediately, whereas NaDCC releases about half of it initially, keeping the balance as preserved ''reservoir chlorine''; after the original FAC has been used up, the reservoir chlorine is released, with this process continuing until the FAC is depleted.[7,8]

Another difference between the two products is the effects of solution pH on performance. The disinfection effectiveness of chlorine-releasing agents is known to decrease in alkaline pH levels and increase in acidic pH levels.[12] Bleach and other hypochlorites are alkaline and tend to increase the solution pH level, which in turn promotes the dissociation of HOCl to the hypochlorite ion (OCl^-).[7,14] NaDCC tablets provide an acidic solution—the reduced pH promotes the formation of undissociated HOCl.

Earlier studies have stated that two main factors determine the effectiveness of chlorine disinfectants: (i) the rate of diffusion of HOCl molecules into the cell of a microorganism and (ii) the degree of interaction with cell components.[6] These depend on pH, which determines the concentration of undissociated HOCl molecules. In addition to pH, the presence of organic matter will impact the efficiency of chlorine-releasing compounds.[12]

Tests have shown that NaDCC tablet shelf life in temperate and tropical climates is five years, whereas the recommended life for bleach is six months after opening the container.[7] NaDCC is also resistant to degradation from sunlight—this is another factor that makes NaDCC a stable source of FAC in solution.[12,15]

Compact and stable NaDCC tablets can be mixed with water more accurately and safely, resulting in less misdosing and spillages, than compared to mixing liquid bleach with water.[7,14] A disadvantage of NaDCC is the relatively high cost.[15]

Disinfection contact time

For all disinfectants, including NaDCC, the required contact time and solution concentration depend on the target microorganisms to be eliminated. Contact times and how to prepare solutions in necessary concentrations are given on product labels; typical contact times for solutions of 1000-5000 ppm FAC range from 1 to 10 minutes to inactivate a wide range of different microorganisms.[5,11]

IV. Effects on Human Health and the Environment

An overview is provided here of the hazards of the main ingredient of the NaDCC tablets (i.e., troclocene sodium, also known as sodium dichloroisocyanurate) and the main ingredient in bleach (sodium hypochlorite). It should be noted that during use, both are diluted. Bleach is further diluted by adding water, and NaDCC tablets dissolve in water to produce several isocyanurates and chlorinated isocyanurates as well as hypochlorous acid, which provides the "reservoir" of FAC. The hazards described below are for the dry NaDCC tablet and the undiluted bleach with an approximate concentration of 5%.

Although there are advantages to using a disinfectant in tablet form, NaDCC tablets have health and environmental hazards. There are a number of hazards to be aware of, and more scientific studies are needed to more comprehensively evaluate the acute and chronic human health effects of NaDCC.

European Union classification for NaDCC and sodium hypochlorite

According to the harmonized classification under the EU REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) program, troclocene sodium (NaDCC) is very toxic to aquatic life, causes severe skin burns and eye damage, is harmful if swallowed, and may cause respiratory irritation. Accordingly, it has been assigned the signal word "Danger!" and the following three pictograms under EU's Harmonized Classification and Labelling (CLH) system.[4]

Oxidizing | Harmful | Environmental hazard

Figures 4, 5, and 6. The EU's CLH pictograms assigned to triclocene sodium (NaDCC).

Sodium hypochlorite also causes severe skin burns and eye damage and is very toxic to aquatic life. Additionally, this substance causes skin irritation, may cause respiratory irritation, and may be corrosive to metals. The signal word "Danger!" and the following three pictograms have been assigned to sodium hypochlorite.[16]

Corrosive | Harmful | Environmental hazard

Figures 7, 8, and 9. The EU's CLH pictograms assigned to sodium hypochlorite.

Case reports of human health impacts of bleach and NaDCC

Bleach has been used for decades. Each year from 2012 to 2016, poison control centers in the U.S. received between 43,000 and 46,000 bleach-related inquiries. There were between 43,000 and 46,000 inquiries about bleach to poison control centers in the US each year from 2012 to 2016.[17] While ingestion of small amounts is unlikely to cause significant toxicity, larger amounts may cause corrosive gastrointestinal injury and systemic effects.[18] Injury and irritation due to respiratory, skin and eye exposure are common.[19]

There is far less information available about the human health impacts of NaDCC than about bleach. The following three NaDCC-related case reports have been identified in scientific literature.

- **Case 1: A child's acute lung injury**
  Wiel et al (2013) reported an acute lung injury case of a 5-year-old child who accidentally inhaled gas formed after a reaction of NaDCC tablets with water.[20]

- **Case 2: An ophthalmologist's asthma and atopic dermatitis after exposure to NaDCC disinfectant**
  Goverdhan & Gaston (2003) described an ophthalmologist who developed severe asthma and atopic dermatitis after using NaDCC to disinfect tonometer heads. The exposure was not acute but chronic, occurring intermittently over a six-year period.[21]

- **Case 3: Reactive airway dysfunction syndrome (RADS) caused by exposure to dishwasher detergent powder containing NaDCC**
  Hannu et al (2012) discussed the case of a 43-year-old apprentice cook who developed respiratory symptoms immediately after exposure to detergent powder containing sodium metasilicate and NaDCC. Powder became airborne after shaking the package vigorously. Inhalation of dust caused immediate, intense

coughing. Subsequent spirometry and histamine challenge tests showed more extensive respiratory function impairments. Five years after the incident, spirometry continued to show respiratory obstruction and the RADS diagnosis was made.[22]

Respiratory injury due to chlorine gas inhalation

When using NaDCC and bleach for disinfection of surfaces, the concern for respiratory injury is associated with the generation of and exposure to chlorine gas. As discussed above, chlorine gas can be released from any solution with free chlorine, including those containing hypochlorous acid.

Chlorine (Cl_2) is moderately water soluble and thus can be inhaled deeply into the respiratory tract (see Figure 10). In addition to the water solubility and particle size, the exposure depends on various factors such as concentration, duration of exposure, and whether an exposure occurs in an enclosed space. These factors determine the degree of injury after acute inhalation exposure.[23]

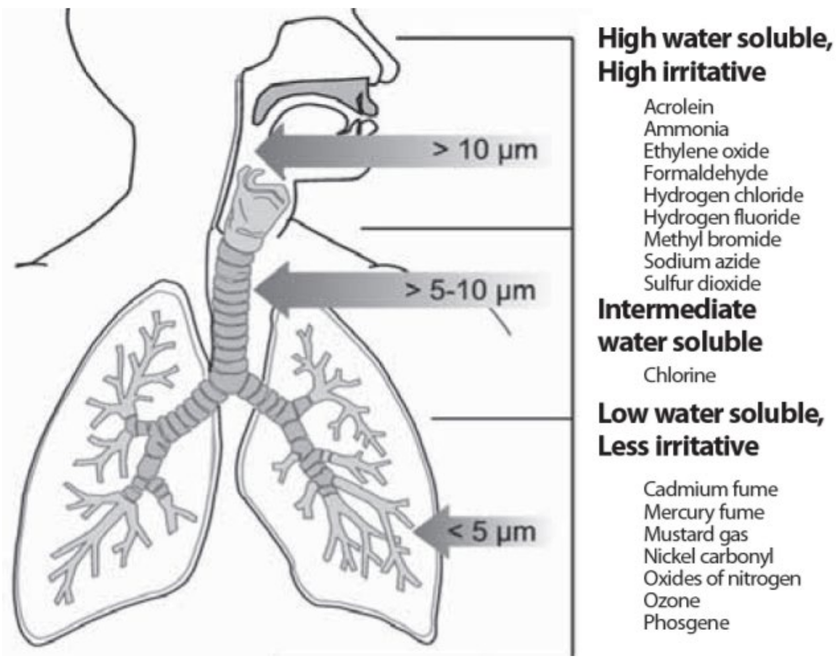


Figure 10. Distribution of irritant gases and dust particles and locations of respiratory injury.

White and Martin (2010) published Figure 11 below, illustrating a potential mechanism for respiratory injury after chlorine gas inhalation exposure.[19] It shows that toxic effects may not be limited to chlorine gas only, but could also be associated with hypochlorous acid (HOCl) and other chlorine species.

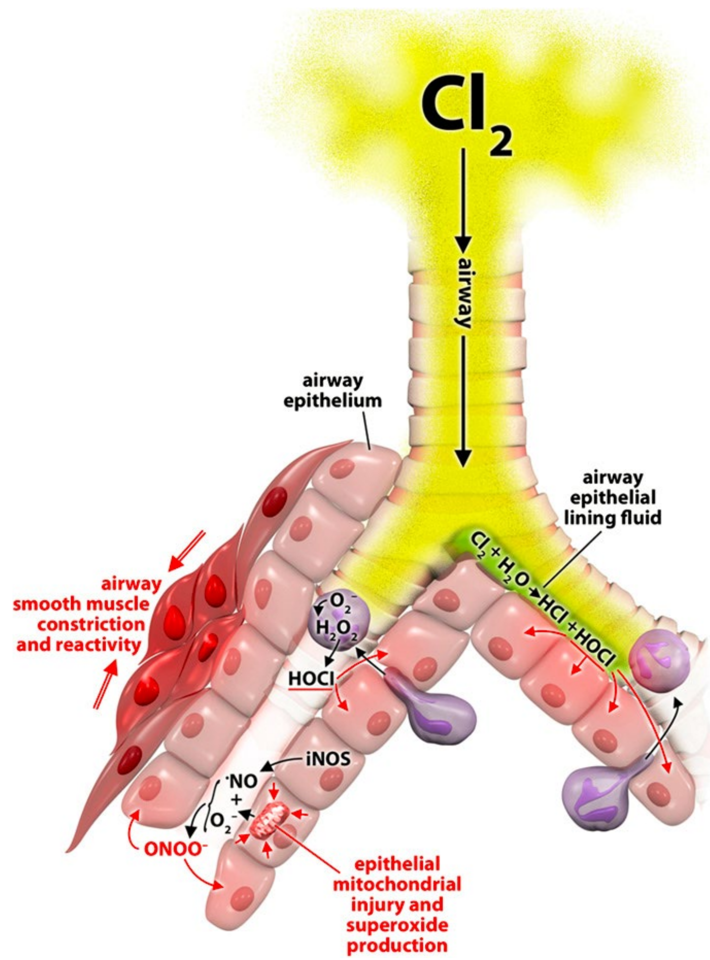


Figure 11. Postulated mechanisms by White and Martin for respiratory tract injury due to chlorine (Cl_2) gas inhalation which leads to the formation of HCl and HOCl on the epithelial lining fluid. As indicated, both Cl_2 and HOCl can react with various airway lining constituents, forming reactive oxygen species (ROS) and nitrogen.[19]

As mentioned previously, chlorine gas is moderately water soluble; it can form HOCl and hydrochloric acid (HCl) after dissolving into the airway surface liquid when contacting mucosal surfaces and airways, as follows:[19]

$$Cl_2 + H_2O \rightleftharpoons HCl + HOCl$$

chlorine *water* *hydrochloric acid* *hypochlorous acid*

$$2HOCl \rightleftharpoons 2HCl + O_2$$

Hypochlorous acid *hydrochloric acid* *oxygen*

In the respiratory system, oxidative injury is likely involved, as chlorine gas can combine with reactive oxygen species and other airway lining fluid constituents and form a wide range of reactive oxidants. In the respiratory tract, the lining's direct oxidative injury may occur immediately after an acute Cl_2 exposure, but further damage may continue to occur, resulting a more severe lung injury. By similar mechanisms, chlorine exposure can injure the lower airways, eyes, skin, and upper airways.[19]

Several agencies have created exposure limits to provide guidance for minimizing potential respiratory impacts associated with inhalation of airborne chlorine:

- The Occupational Safety and Health Administration (OSHA) developed permissible exposure limits (PELs) for chlorine that include a short-term exposure limit (STEL) (up to 15-minute exposures) of 1 ppm.[24]

- The threshold limit values (TLVs®) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) are lower than those developed by OSHA (e.g., a STEL of 0.4 ppm and a TWA of 0.1 ppm).[25] The TLVs were selected "in order to minimize eye, nasal, and lower respiratory tract irritation … Short-term 'peak' exposures to chlorine appear to be important in the initiation of Reactive Airways Dysfunction Syndrome (RADS), and the resulting airway hyperresponsiveness may persist for several years."[26]

- The National Institute for Occupational Safety and Health (NIOSH) has published a recommended exposure limit (REL) for chlorine which is a STEL of 0.5 ppm.[27]

Odor detection threshold of chlorine gas ranges from 0.1 to 0.3 ppm.[19] At 1–3 ppm, there is mild mucus membrane irritation. Levels of 1–2 ppm of chlorine are considered ''burdensome" and ''irritating." At these levels mild mucus membrane irritation occurs and can be tolerated for about one hour.[19]

V. TURI Laboratory Evaluation to Assess Airborne Chlorine Exposures

Objective of the laboratory evaluation

Experimental disinfection tasks were conducted in the TURI Laboratory's simulated bathroom. Two different chlorine-releasing disinfectants were used: solid BruTab6S tablets (NaDCC) and liquid Clorox bleach (sodium hypochlorite). The objective of this work was to assess airborne chlorine exposures generated by these two disinfectants when used in three different concentrations.

Methods

The disinfection procedure consisted of first preparing a test concentration of one of the disinfectants and then applying it using two techniques: (i) the prepared solution poured into an open bucket and applied onto the bathroom surfaces with a brush, and (ii) the prepared solution applied with a spray bottle and similarly brushed onto the surfaces.

Each disinfection experiment consisted of three phases and lasted a minimum of 45 minutes: (i) solution preparation (about 5 min), (ii) disinfection procedure of the bathroom with the above techniques (20 min), and (iii) disinfectant wet contact time in the bathroom (20 min).

Disinfectant based on solid tablets

The active ingredient of BruTab6S is NaDCC. Three different FAC concentration solutions—2153 ppm, 4306 ppm, and 5382 ppm—were prepared according to the manufacturer's instructions on the product label.[5] The solutions were newly prepared before each experiment.

Bleach disinfectant

Two bleach solutions—FAC concentrations of 2036 ppm and 5182 ppm—were prepared. The reasons for choosing the specific 5182-ppm concentration was that it was at least 5000 ppm, thus considered for high-level disinfection, and it was convenient to prepare from the base solution (Clorox bleach, 5.7% available chlorine) by dissolving 1 part of bleach in 10 parts of water. The other bleach concentration (2036 ppm) was selected to approach NaDCC's lower concentration.

Measuring airborne chlorine exposures

Figure 12. MultiRAE PID device used to measure airborne chlorine.

Airborne chlorine exposures were measured using a direct reading device—a 120-volt MultiRAE 4-gas meter with a photoionization detector (PID) (see Figure 12). The device was equipped with an electrochemical sensor to detect chlorine gas. The sensor's resolution (i.e., the limit of detection) was 0.1 ppm. Anything below 0.1 ppm was recorded as zero on the data log. The device was rented from the Pine Environmental Company in Woburn, Massachusetts. Before the rental, the company performed all required gas calibrations and provided the certificate. The company delivery technician demonstrated how the device detected chlorine gas at 10 ppm.

The device was also equipped with a 10.6-eV photoionization detection lamp to detect volatile organic compounds (VOCs).

The device had a continuous data-logging capability. It was set to record detections once every 10 seconds. Before each experiment, a fresh air calibration was performed for the device. After calibration, the device was placed into a backpack which was worn with the back side in the front so that the instrument's inlet tube was positioned near the breathing zone (Figure 13). The device started to record right after the completion of the fresh air calibration. It was kept on the recording mode for at least 45 minutes during the three experiment phases. The device was taken off of the backpack after the disinfection phase.

Figure 13. Placement of the measuring device during the disinfection phase.

Figure 14. The device in the shampoo/soap holder above the tub during the wet contact time phase.

During the wet contact time phase, the device was first placed on the top of the sink (5 minutes), then on the top of the toilet (5 min), in the shampoo/soap basket above the tub (5 min, Figure 14), and finally held in the hand until the end of the experiment.

After each experiment, the laboratory space was ventilated for a minimum of two hours to ensure that no residual airborne chlorine was detected before a new experiment was started. For bleach, the laboratory was ventilated for approximately 4 hours between the experiments to ensure the removal of all airborne chlorine.

Exposure setting at the simulated bathroom in the TURI Lab

All three phases of the experiment were conducted in the TURI Laboratory's simulated bathroom. The bathroom has a floor area of approximately 3.5 square meters (38 square feet) and contains a porcelain toilet (Figure 15), fiberglass tub, and composite sink on the top of a vanity cabinet. The bathroom surfaces were lightly colored with a water-soluble crayon to simulate dirt.

Figure 15. Disinfection procedure in the simulated bathroom.

Key findings

The key findings are summarized in Tables 1 and 2. Data logs of this work are available from TURI upon request.

Table 1. Average and peak exposures of airborne chlorine and volatile organic compounds (VOCs) measured during disinfection experiments at the TURI Lab.

Available chlorine concentration of the disinfectant solution	Method	Duration	Total number of sampling recordings	Chlorine exposure recordings (ppm) – entire duration		Total number (%) of sampling recordings for chlorine at or above LOD*	VOC exposure recordings (ppm) – entire duration	
				Average	Peak		Average	Peak
NaDCC: 2153 ppm. Eight 3.3g tablets in 1 gallon of water	Bucket & brush	52 min	308	<0.1	0.1	21 (7%)	1	1
NaDCC: 2153 ppm. Two 3.3g tablets in 1 quart of water	Bucket & brush	48 min	288	<0.1	0.1	6 (2%)	1	1
NaDCC: 2153 ppm. Two 3.3g tablets in 1 quart of water	Hand spray & brush	49 min	297	<0.1	0.1	4 (1%)	1	1
NaDCC: 4306 ppm. Eight 3.3g tablets in 2 quarts of water	Bucket & brush	49 min	296	<0.1	0.1	1 (<1%)	1	1
NaDCC: 4306 ppm. Four 3.3g tablets in 1 quart of water	Hand spray & brush	46 min	279	<0.1	0.1	27 (9%)	1	1
NaDCC: 5382 ppm. Ten 3.3g tablets in 2 quarts of water	Bucket & brush	52 min	310	<0.1	0.1	16 (5%)	1	2
NaDCC: 5382 ppm. Five 3.3g tablets in 1 quart of water	Hand spray & brush	51 min	306	<0.1	0.1	4 (1%)	1	2
Bleach: 2036 ppm. 1 part of Clorox 5.7% avail. chlorine to 27 parts of water (37 ml bleach, 1000 ml water)	Bucket & brush	48 min	288	<0.1	0.3	69 (24%)	2	2
Bleach: 2036 ppm. Same as above: 37 ml bleach to 1000 ml water	Hand spray & brush	50 min	301	<0.1	0.5	111 (37%)	1	1
Bleach: 5182 ppm. 1 part of Clorox 5.7% avail. chlorine to 10 parts of water (100 ml bleach, 1000 ml water)	Bucket & brush	47 min	282	0.2	0.7	202 (72%)	2	3
Bleach: 5182 ppm Same as above: 100 ml of bleach to 1000 ml water	Hand spray & brush	49 min	293	0.1	0.6	174 (59%)	1	1

* The lower limit of detection (LOD) for the MultiRAE PID chlorine sensor is 0.1 ppm (100 ppb). Anything below 0.1 ppm was recorded as zero.

Table 2. Median and peak exposures during three different experiment phases for airborne chlorine and volatile organic compounds (VOCs) measured at the TURI Lab.

Available chlorine concentration/ method	Median and peak chlorine recordings during different experiment phases (ppm)			Median (med.) and peak VOC exposure recordings during different experiment phases (ppm)		
	Solution preparation	Disinfection	Wet contact time	Solution preparation	Disinfection	Wet contact time
NaDCC 2153 ppm / bucket (gallon)	<0.1 all	<0.1 (med.) 0.1 (peak)	<0.1 (med.) 0.1 (peak)	0 (med.) 1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)
NaDCC 2153 ppm / bucket (quart)	<0.1 (med.) 0.1 (peak)	<0.1 all	<0.1 (med.) 0.1 (peak)	0 (med.) 1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)
NaDCC 2153 ppm / spray	<0.1 all	<0.1 all	<0.1 (med.) 0.1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)
NaDCC 4306 ppm / bucket	<0.1 all	<0.1 all	<0.1 (med.) 0.1 (peak)	0 (med.) 0 (peak)	0 (med.) 1 (peak)	1 (med.) 1 (peak)
NaDCC 4306 ppm / spray	<0.1 (med.) 0.1 (peak)	<0.1 (med.) 0.1 (peak)	<0.1 (med.) 0.1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)
NaDCC 5382 ppm / bucket	<0.1 (med.) 0.1 (peak)	<0.1 (med.) 0.1 (peak)	<0.1 (med.) 0.1 (peak)	1 (med.) 1 (peak)	1 (med.) 2 (peak)	1 (med.) 2 (peak)
NaDCC 5382 ppm / spray	<0.1 all	<0.1 all	<0.1 (med.) 0.1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)	1 (med.) 2 (peak)
Bleach 2036 ppm / bucket	<0.1 (med.) 0.1 (peak)	<0.1 (med.) 0.1 (peak)	<0.1 (med.) 0.3 (peak)	1 (med.) 1 (peak)	1 (med.) 2 (peak)	2 (med.) 2 (peak)
Bleach 2036 ppm / spray	<0.1 all	<0.1 (med.) 0.1 (peak)	0.1 (med.) 0.5 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)
Bleach 5182 ppm / bucket	<0.1 all	0.1 (med.) 0.4 (peak)	0.3 (med.) 0.7 (peak)	1 (med.) 1 (peak)	2 (med.) 2 (peak)	3 (med.) 3 (peak)
Bleach 5182 ppm / spray	<0.1 all	<0.1 (med.) 0.2 (peak)	0.3 (med.) 0.6 (peak)	0 (med.) 1 (peak)	1 (med.) 1 (peak)	1 (med.) 1 (peak)

Average and peak airborne chlorine exposures

Table 1 shows that the bleach solutions resulted in higher average and higher peak chlorine exposures than the NaDCC tablet solutions.

For the higher FAC concentration of 5182 ppm, the bleach solution generated an average chlorine exposure of 0.2 ppm when applied with an open bucket and 0.1 ppm when applied as a spray. For this same bleach concentration, the highest peak chlorine exposure was 0.7 ppm with an open bucket and 0.6 ppm with spray. The lower bleach concentration (2036 ppm) resulted in a peak chlorine exposure of 0.5 ppm using the spray application.

The highest peak chlorine exposure recording for all NaDCC FAC concentrations tested was 0.1 ppm (the LOD). All average chlorine exposures were below 0.1 ppm.

Chlorine exposures at or above the 0.1 ppm limit of detection

Table 1 also shows that for all bleach solutions used in the experiment, the device detected more chlorine exposures either at or above the LOD (0.1 ppm) than for those solutions made from NaDCC tablets. For the lower FAC concentration bleach solutions, the LOD was reached or exceeded 24% of the time when using the open bucket technique and 37% of the time using the spray technique. The LOD was reached or exceeded 72% of the time for the higher FAC concentration bleach solutions when using the open bucket technique.

For all NaDCC solutions, the device recorded significantly less chlorine at or above 0.1 ppm than for bleach. The detected chlorine exposure and frequency were similar across all three FAC concentrations, with a peak measurement of 0.1 ppm at all FAC concentrations and only 3-5% of measurements above the LOD (see Table 1).

Chlorine exposures at the different experiment phases

Table 2 shows that higher chlorine exposures—both average and peak exposures—were recorded during the disinfectant contact time phase than during the other two phases. Very little airborne chlorine was recorded during the solution preparation phase for either disinfectant. Some chlorine exposures were recorded during the disinfection phase, in particular for bleach.

VOC exposures

Tables 1 and 2 show that VOCs were generated both with bleach and NaDCC solutions. The average VOC level for all NaDCC solutions was 1 ppm. For bleach solutions applied with an open bucket, the average VOC exposure was 2 ppm. For bleach solutions applied with spray, the average VOC exposure was 1 ppm.

Discussion

Tables 1 and 2 show that NaDCC solutions resulted in lower concentrations of airborne chlorine and fewer chlorine concentrations at or above the LOD than for bleach solutions. The technique applied—open bucket or spray—did not seem to notably affect the results for NaDCC.

Tables 1 and 2 also show that airborne VOCs were detected in all experiments at levels of 1-2 ppm. Identification of specific VOCs or other airborne contaminants was outside the scope of this project and is an area for additional study. Some researchers have hypothesized that chlorinated organics and inorganics, as well as nitrogenated compounds, could contribute to adverse health impacts from cleaning and disinfecting with bleach.

Table 2 shows that the highest airborne chlorine exposures occurred during the disinfectant wet contact time phase. This finding can inform worksite practices: Unless necessary, employees should avoid disinfectant wet contact areas.

The OSHA permissible exposure limit of 1 ppm was not reached in any of the experiments. Both the ACGIH STEL TLV and the NIOSH STEL REL were exceeded for bleach but not for NaDCC. In addition, the experiment time (a minimum of 45 minutes) was designed to be long enough to detect airborne chlorine. The experimental disinfection phase (20 minutes) and contact time phase (20 minutes) were likely longer than they would be in a real-life setting.

Significance of bathroom surface cleanliness

It is good practice to clean surfaces before disinfection. This is not always performed in the real world, so in the TURI Lab tests, water-soluble color crayons were applied lightly on bathroom surfaces to simulate occasional soil on the surface. The presence of organic material can affect the stability of FAC in the disinfectant solution and thus can generate airborne chlorine.[12] No control was performed, and only a few marks were made on surfaces; it is unknown if this impacted results, and could be an area for further research.

The very first open bucket experiment was conducted with the lowest NaDCC concentration (2153 ppm) and airborne chlorine was detected 21 times at the LOD. The highest NaDCC concentration (5382 ppm) with an open bucket resulted in fewer readings at the LOD (16 times). The reasons for this could be that during the first experiment the simulated bathroom had been unused for quite some time (several months) and it had a layer of dust and dirt on it, and more water was used (1 gallon). Because the 1-gallon water bucket was difficult to handle, the amount of water was reduced from 1 gallon to 2 quarts for the subsequent bucket-technique experiments. The NaDCC 2153-ppm bucket experiment was also repeated with less water. This test detected airborne chlorine only 6 times at the LOD.

Conclusions

This work aimed to assess airborne chlorine exposures generated by NaDCC and bleach disinfectants in different concentrations using two different application techniques. Under experimental use conditions, NaDCC solutions resulted in lower airborne chlorine exposures and fewer detections at or above the measuring instrument's limit of detection than bleach solutions.

References

1. Quinn MM, Henneberger PK, National Institute for Occupational Safety and Health, National Occupational Research Agenda Cleaning Disinfecting in Healthcare Working Group, Braun B, Delclos GL, et al. Zock JP. Cleaning and disinfecting environmental surfaces in health care: Toward an integrated framework for infection and occupational illness prevention. *Am J Infect Control*. 2015; 43(5):424-34. DOI: 10.1016/j.ajic.2015.01.029. PMID: 25792102.
2. Association of Occupational and Environmental Clinics. Benzalkonium chloride. AOEC Exposure code 322.321. Available at: http://www.aoecdata.org/ExpCodeLookup.aspx. Accessed: June 18, 2019.
3. Association of Occupational and Environmental Clinics. Sodium hypochlorite (bleach). AOEC Exposure code 322.10. Available at: http://www.aoecdata.org/ExpCodeLookup.aspx. Accessed: June 18, 2019.
4. European Chemicals Agency. Substance Infocard: Troclosene sodium. Available at: https://echa.europa.eu/substance-information/-/substanceinfo/100.018.880. Accessed: July 19, 2020.
5. Brulin. BruTab6S (product label). 2018. Available at: http://bhcinc.com/wp-content/uploads/pdf/161021.Carton%20Insert.13.1g.3.3g.pdf. Accessed: July 26, 2019.
6. Bloomfield SF, Uso EE. The antibacterial properties of sodium hypochlorite and sodium dichloroisocyanurate as hospital disinfectants. *J Hosp Infect*. 1985; 6(1):20-30. DOI: 10.1016/s0195-6701(85)80014-1. PMID: 2859319.
7. Clasen T, Edmondson P. Sodium dichloroisocyanurate (NaDCC) tablets as an alternative to sodium hypochlorite for the routine treatment of drinking water at the household level. *Int J Hyg Environ Health*. 2006; 209(2):173-81. DOI: 10.1016/j.ijheh.2005.11.004. PMID: 16387550. Accessed September 7, 2020, at https://www.unicef.org/cholera/Annexes/Supporting_Resources/Annex_9/Clasen-NaDCC2.pdf
8. United States Environmental Protection Agency. Pesticide product labels. Ecolab NaDCC: https://www3.epa.gov/pesticides/chem_search/ppls/001677-00255-20160629.pdf. Medentech Korkleen 2: https://www3.epa.gov/pesticides/chem_search/ppls/071847-00007-20180806.pdf.
9. Brulin. BruTab6S. Product number: 161037 / 161021 / 161034. Safety data sheet. 2018. Available at: http://bhcinc.com/download/brutab-6s-161021-sds-english/. Accessed: June 6, 2019.
10. Stafford U. A tablet composition (patent). World Intellectual Property Organization. 2010. Available at: https://patents.google.com/patent/WO2010113144A2/en. Accessed: June 6, 2019.

11. Rutala W, Weber D. Guideline for Disinfection and Sterilization in Healthcare Facilities. The Healthcare Infection Control Practices Advisory Committee (HICPAC). US Department of Health and Human Services, Centers for Disease Control and Prevention (CDC), 2008, updated May 2019. Available at: https://www.cdc.gov/infectioncontrol/pdf/guidelines/disinfection-guidelines-H.pdf. Accessed: September 7, 2020.
12. Dychdala G. "Chlorine and chlorine compounds." In: Block S, ed. *Disinfection, Sterilization and Preservation,* 5th ed. Philadelphia, PA, USA: Lippincott Williams & Wilkins, 2001, pp. 135–57.
13. Hoffman PN, Death JE, Coates D. "The stability of sodium hypochlorite solutions." In: Collins CH, Allwood MC, Bloomfield SF, Fox A, eds. *Disinfectants: their use and evaluation of effectiveness.* London: Academic Press, 1981, pp. 77-83.
14. Coates D. A comparison of sodium hypochlorite and sodium dichloroisocyanurate products. *J Hosp Infect*. 1985; 6(1):31-40. DOI: 10.1016/s0195-6701(85)80015-3. PMID: 2859320.
15. Lantagne DS, Cardinali F, Blount BC. Disinfection by-product formation and mitigation strategies in point-of-use chlorination with sodium dichloroisocyanurate in Tanzania. *Am J Trop Med Hyg*. 2010; 83(1):135-43. DOI: 10.4269/ajtmh.2010.09-0431. PMCID: PMC2912590. PMID: 20595492.
16. European Chemicals Agency. Substance Infocard: Sodium hypochlorite. Available at: https://echa.europa.eu/substance-information/-/substanceinfo/100.028.790.
17. Gummin D, Mowry J, Spyker D, Brooks D, Fraser M, Banner W. 2016 Annual Report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 34th Annual Report. *Clin Toxicol (Phila).* 2017 Dec; 55(10):1072-1252. DOI: 10.1080/15563650.2017.1388087. PMID: 29185815.
18. Slaughter R, Watts M, Vale JA, Grieve JR, Schep LJ. The clinical toxicology of sodium hypochlorite. *Clin Toxicol.* 2019; 57(5):303-11. DOI: 10.1080/15563650.2018.1543889. PMID: 30689457.
19. White CW, Martin JG. Chlorine gas inhalation: human clinical evidence of toxicity and experience in animal models. *Proc Am Thorac Soc*. 2010; 7(4):257-63. DOI: 10.1513/pats.201001-008SM. PMCID: PMC3136961. PMID: 20601629.
20. Wiel E, Sicot J, Leteurtre S, Binoche A, Nisse P, Assez N. Sodium dichloroisocyanurate-induced acute lung injury in a child. *Arch Pediatr*. 2013; 20(4):375-7. DOI: 10.1016/j.arcped.2013.01.011. PMID: 23433843.
21. Goverdhan S, Gaston H. Sanichlor-induced atopic dermatitis and asthma in ophthalmologists. *Eye (Lond)*. 2003; 17(1):108-9. DOI: 10.1038/sj.eye.6700228. PMID: 12579187.
22. Hannu TJ, Riihimaki VE, Piirila PL. Reactive airways dysfunction syndrome from acute inhalation of a dishwasher detergent powder. *Can Respir J*. 2012; 19(3):e25-8. DOI: 10.1155/2012/150919. PMCID: PMC3418100. PMID: 22679618.
23. Gorguner M, Akgun M. Acute inhalation injury. *Eurasian J Med*. 2010; 42(1):28-35. DOI: 10.5152/eajm.2010.09. PMCID: PMC4261306. PMID: 25610115.
24. Occupational Safety and Health Administration. Permissible Exposure Limits – Annotated Table Z-1. Available at: https://www.osha.gov/annotated-pels/table-z-1. Accessed: July 26, 2019.
25. American Conference of Governmental Industrial Hygienists (ACGIH). 2019 TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. Cincinnati, 2019.
26. American Conference of Governmental Industrial Hygienists (ACGIH). Documentation of the Threshold Limit Values and Biological Exposure Indices. Cincinnati, 2018.
27. National Institute for Occupational Safety and Health. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication Number 2005-149, September 2007. Accessed at: https://www.cdc.gov/niosh/npg/default.html

About the Toxics Use Reduction Institute

The Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell provides resources and tools to help Massachusetts businesses and communities make the Commonwealth a safer and more sustainable place to live and work. Established by the state's Toxics Use Reduction Act of 1989, TURI provides research, training, technical support, laboratory services and grant programs to reduce the use of toxic chemicals while enhancing the economic competitiveness of Massachusetts businesses. Learn more at www.turi.org.

TURI
TOXICS USE REDUCTION INSTITUTE
UMASS LOWELL

Toxics Use Reduction Institute
University of Massachusetts Lowell
The Offices at Boott Mills West
126 John Street, Suite 14 (2nd Floor)
Lowell, MA 01852-1152
(978) 934-3275 • www.turi.org