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Chlorine gas and ultrafine particle emissions from bleach disinfection: occupational exposure risks and safety strategies

Cleaners are frequently exposed to a wide range of airborne agents, including respiratory sensitizers and irritants. Notably, exposure to bleach and other chlorine-based disinfectants have been associated with an increased risk of respiratory conditions. However, much of the available evidence relies on self-reported exposure data, which may introduce bias toward cleaning agents with more pronounced odors, leaving the causal agents largely unidentified. Furthermore, the underlying mechanistic pathways remain poorly understood, hindering the development of effective mitigation strategies. This study aimed to characterize the emission of chlorine gas and ultrafine particles (UFPs) during routine disinfection procedures to enhance the understanding of occupational exposure and to inform the development of targeted mitigation measures. Measurements were conducted in a 1.80 m × 1.20 m × 2.20 m plexiglass chamber with an air exchange rate of 0.2 h^{-1}. The chamber contained a polypropylene tub (1 m^2 surface area), an Airpur air purifier, a Condensation Particle Counter, a Scanning Mobility Particle Sizer, a Fast Mobility Particle Sizer, two GasBadgePro detectors, a luminosity sensor, and a Radium Sanolux lamp. Prior to each experiment, the chamber was purged to minimize particle concentrations, and a freshly prepared 0.5% sodium hypochlorite solution was introduced via tubing. Four experimental conditions were tested: ambient temperature (26℃), elevated temperature (38.5℃), light exposure, and hydrochloric acid interaction (15 mL, 10% v/v). Particle concentrations, size distributions, and chlorine gas emissions were measured over time to calculate emission factors. Additionally, real-world validation experiments were conducted in two sealed office settings, one before cleaning and one after, under conditions mimicking actual disinfection.

At room temperature UFP emissions were detected, but no chlorine gas was released. At elevated temperature (38.5℃), UFP emissions increased significantly, with an emission factor of 1×1011 part/min, while chlorine gas emissions reached 0.38 ppm. The increased temperature likely destabilized hypochlorous acid, leading to enhanced volatilization and secondary aerosol formation. The rise in UFPs suggests that temperature plays a key role in accelerating volatile organic compound oxidation, promoting ultrafine particle formation. The simultaneous detection of chlorine gas under high-temperature conditions raises concerns about occupational exposure risks, particularly in tropical climates and enclosed indoor environments with limited ventilation. UV radiation exposure also resulted in a significant increase in UFP formation, with an emission factor of 9.78×1010 part/min, but no detectable chlorine gas emissions.

The introduction of organic contaminants, simulated using HCl to mimic the acidic nature of vomit, resulted in the highest chlorine gas emission (9.45×106) and concentration (9.9 ppm) recorded in the study, while no UFPs were detected. This suggests that acidic biological fluids significantly enhance chlorine gas formation while suppressing the oxidation pathways that generate UFPs.

In Office 1 (before cleaning), a chlorine gas emission of 4.12×105 was detected reaching a concentration of 0.5 ppm, likely due to reactions between bleach and organic residues on the floor. Simultaneously, a UFP emission of 2.46×109 was recorded. In contrast, in Office 2 (after cleaning), no chlorine gas emissions were detected, but a higher UFP emission (3.79×10^9 part/min) was observed. This supports the hypothesis that organic contaminants contribute to chlorine gas formation, while clean surfaces favor secondary aerosol formation.

The results suggest that two distinct pathways drive emissions: chlorine gas is primarily released when bleach reacts with acidic contaminants or organic residues, while UFP formation is promoted under conditions of high temperature, UV radiation, and clean surfaces. The observation that chlorine gas and UFPs were rarely detected together reinforces this hypothesis.

Chlorine gas emissions peak when bleach is applied to contaminated surfaces, exceeding occupational exposure limits by nearly 20 times, while no chlorine gas was detected on pre-cleaned surfaces. This underscores the necessity of strict cleaning protocols to minimize exposure risks. Conversely, UFP emissions were highest in clean environments, indicating their formation is driven by secondary chemical reactions rather than direct contamination. Unlike chlorine gas, which causes acute airway irritation, UFPs penetrate deep into the lungs, leading to oxidative stress and inflammation, posing potential long-term health risks. There are currently no regulatory exposure limits for UFPs, highlighting the urgent need for research on their health impacts and the development of safety guidelines. Effective ventilation is crucial for reducing exposure to both chlorine gas and UFPs, and safer disinfectant alternatives should be considered.

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