2022 Novel Non-chemical Sanitation Methods

Request: A literature review on novel (i.e., non-chemical) sanitation technologies food (especially dairy) manufacturing environments such as blue light.

Response:

Some technologies appear promising (including blue light), but with some caveats:

- In many cases, the efficacy of these technologies against a pathogen was not tested on a surface (it was tested in suspension in media or on smooth coupons without a lot of surface variability).
- The technologies may not have been tested within a biofilm or in food residue on a surface, which might the ability of these technologies to reach the pathogen.
- One concern with many of these technologies is that they may be unable to target niche areas within the food manufacturing environment.
- In some cases (UV light, for example), worker safety can be a concern.
- There may be fairly limited (or no) experience with the use of some of these technologies in food manufacturing environments at this time.
- The impact of these technologies on food manufacturing equipment may not be currently known. Some may damage equipment, for example, which might result in new bacterial harborage sites
- Commercial scale equipment suitable for a food manufacturing facility may not yet be available.

Some recent reviews provide useful information:

- Liu (2021) provides a good overview of different physical methods that might be used for bacterial biofilm control (Liu et al.). In particular, Table 1 in this article outlines bacterial biofilms (*E. coli, L. monocytogenes, Salmonella*, etc.) that have been tested with various physical antimicrobial methods (irradiation, ultrasound, plasma, etc.).
- The ability of various physical interventions (pulsed electric field, irradiation, cold plasma) against *Salmonella* are discussed in one paper, but the focus seems to be more on *Salmonella* within food rather than on food contact surfaces (Bermudez-Aguirre and Corradini, 2012)
- An older document commissioned by FDA talks about the kinetics of inactivation of microorganisms by alternative food processing technologies, but focuses mostly on microorganisms within foods, not on food processing surfaces (Institute for Food Technologists, 2000)
- This review (Oliveira 2020) summarizes the use of various technologies (including pulsed UV light, ultrasonic fogging, gaseous ozone, etc.) on **decontamination of air** in cold rooms within food processing environments (including cheese facilities). It doesn't discuss pathogens very much, though.

Other articles which may be older and/or less applicable to your question include the following:

- This magazine article (Fox 2021) discusses "Sanitation in the COVID era" but doesn't talk about novel sanitation technologies.
- This older magazine article "Cleaning without Chemicals" (Pehanich, 2006) discusses ozone, wet and dry steam, and silver ion technology in food manufacturing facilities.

- Holah (2014) is a slightly older but very detailed book chapter that focuses mainly on chemical sanitation but does talk a bit about UV and ozone use in section 9.8 (Holah, 2014).

Ozonation

Technically, this would be considered a chemical method of disinfection, but may be of interest:

- (Eglezos and Dykes, 2018) discusses the use of gaseous ozone in a cheese processing facility, finding it could significantly reduce the prevalence of the pathogen in a facility. After 1 year of use, there were "no deleterious effects noted on floors, walls, drains or equipment".
- (de Candia et al., 2015) demonstrated that high viable loads of *L. monocytogenes* can be removed on contaminated food contact surfaces (glass, polypropylene, stainless steel, etc.) with cold gaseous ozone treatments at low concentrations.
- (Nicholas et al., 2013) describes the efficacy of gaseous ozone and "Open Air Factor" (OAF; a collection of highly reactive chemical species that are generated when ozone reacts with a compound containing unsaturated hydrocarbons) against surface-attached *L. monocytogenes*. In this study, the OAF was produced from d-limonene. The authors concluded "While gaseous ozone treatment (45 ppm) is effective for surface disinfection, it is not feasible to apply this on a large scale due to toxicity effects. This study has demonstrated the potential application of OAF as an alternative technology as it can be used while personnel are present. For more about OAF, see this paper.
- (Crapo et al., 2004) discusses the efficacy of using ozonated water as a bactericidal agent for sanitizing food contact surfaces (and for raw seafood), concluding that it was about as effective as chlorine in reduction Listeria innocua levels on stainless steel surfaces but less effective on plastic cutting boards. The authors concluded that the use of ozone in food processing operations where bacteria exist within organic matter can be difficult, so they recommend its use on cleaned surfaces only.
- (Khadre et al., 2001) reviews ozone and how it can attack bacteria. Tables 1 and 2 show its activity against Gram-positive and Gram-negative bacteria, respectively. It has some activity against spores but is more effective against vegetative cells.

Ultrasound

Few studies have investigated the use of ultrasound for decontamination/sanitation of surfaces relevant for food manufacturing. In some cases, low-power ultrasound has been shown to actually increase microbial growth. Ultrasound has the advantage of being able to reach crevasses that might not be easily reached by conventional cleaning. Ultrasonic cleaning baths in which other chemicals are added can be effective for decontaminating items like plastic buckets and conveyer belts (Chemat et al., 2011)

- Section 3.2.2 of Chemat 2011 discusses the use of power ultrasound for surface decontamination (Chemat et al., 2011).
- Efficacy of ultrasound plus disinfectants (acidic electrolyzed water, ozone water) against *Salmonella* or *S. aureus* biofilms on stainless steel are discussed in one recent paper (Shao et al.,

2020). In their work, ultrasound alone was not very effective against formed biofilms, but a synergistic effect was seen when combined with acidic electrolyzed water.

- Airborne acoustic ultrasound and plasma activated water showed synergistic activity against *E. coli* biofilms on stainless steel or glass coupons in another paper (Charoux et al., 2020).

Electrolyzed water

A few papers tested the use of electrolyzed water and might be of interest.

- (Rahman et al., 2016) discusses use of electrolyzed water as a novel sanitizer in the food industry, focusing largely on its on food itself but with some discussion of use on surfaces against *E. coli, Salmonella, Listeria*, etc.
- Another study compared the use of electrolyzed water alone and in combination with ultrasound against *Salmonella* or *S. aureus* biofilm on stainless steel (Shao et al., 2020).

Cold plasma

This technology looks promising but does not yet appear ready for commercial application for food processing.

- (Schnabel et al., 2019) looked at plasma-processed air and water for potential utility for sanitation of food processing surfaces and the environment. While promising, the paper concludes "The technical implementation and up-scaling of PPA/PTW-technology into industrial processes will be the future challenge.
- Thirumdas (2015) is a detailed review article on cold plasma, primarily on food products but also on packing materials and in wastewater. Table 1 presents information on the efficacy of cold plasma against various microbes on food (Thirumdas et al., 2015). At the time of this publication, the authors state "Although cold plasma technology is not yet used commercially on a large scale, the equipment should be readily scalable"
- (Katsigiannis et al., 2021) found cold plasma was able to decontaminate stainless steel food processing surfaces contaminated with *L. monocytogenes* and *Salmonella*. The distance from the source needed to be within 5 mm to achieve >2 log reductions for these pathogens. The paper concludes "The results of this study indicate that indirect CAP devices using ambient air are ideal for the treatment of uniform surfaces and could potentially be introduced at strategic points within the food production chain to offer continuous in-line decontamination of food-contact surfaces, minimizing food contamination during processing. Such efforts would certainly reduce down-time associated with current sanitation processes, thus enhancing production. In essence, CAP technology warrants further attention from the food industry and could help it reach future food security targets."
- (Moldgy et al., 2020) found that cold plasma could decontaminate stainless steel surfaces contaminated with feline calicivirus and *Salmonella* spp. as model organisms.

UV light (~200 to 400 nM)

UV light is a relatively mature technology that is already in use already as an alternative or addition to chemical sanitation in some food processing environments. UV light can be produced with mercury vapor lamps (which can leave mercury resides and have a limited life span) or with light emitting diodes (LEDs), which are not hazardous, compact, and have a long lifespan (Prasad et al., 2020). The can be used in air ventilation systems and for water treatment. UV light has a low penetration depth (a few mm) and is hazardous to humans.

- Koca (2018) reviews the use of UV light in dairy processing and includes discussion of its use in sanitation of equipment and packaging.
- A recent review discusses effects of UV light emitting diodes on various microbes (Hinds et al., 2019).
  - The most lethal wavelengths against bacteria fall in the UVC range, particularly 260-265 nm where DNA is damaged.
  - Table 2 of this document discusses studies which have tested UV light against specific microbes in "food safety applications", including surface decontamination.
  - The table suggests efficacy of UV light against *E. coli O157:H7, Salmonella, Listeria monocytogenes* (which proved somewhat resistant), and *Campylobacter* spp. on surfaces.
- Shin (2016) discusses the effect of different UVC doses against E. coli O157:H7, *Salmonella*, and *L. monocytogenes* on solid media (Shin et al., 2016) (also cited in the Hinds 2019 reference).
- This paper discusses the use of UV light-emitting diodes in food production (D'Souza et al., 2015).
- Another (older) paper (Koutchma 2008) reviews the use of UV light in food processing, concluding "To predict UV disinfection rates on food surfaces, more kinetic inactivation data need to be obtained for pathogen and spoilage microorganisms, taking into account interactions between microorganisms and surface materials, such as shielding effects from incident UV and their dependency on surface structure or topography.
- UVC (<280 nm) appears to be effective against norovirus on stainless steel surfaces (Park et al., 2015).
- The susceptibility of *Campylobacter* to high-intensity near-UV/visible light (395 nm) on contact surfaces has been investigated; it appears that UV light was effective against this organism on surfaces (Haughton et al., 2012).
- Koutchma (2014) discusses UV treatment of air, water, and surfaces (including food contact and non-food contact surfaces and shows examples of equipment that might be used in food processing facilities (Koutchma, 2014).

Pulsed light

Pulsed light (PL) is composed of intense light pulses in the infrared, visual or UV regions which can rapidly kill bacteria. It has been tested to kill pathogens (and destroy allergens) on equipment surfaces and packaging materials. It is limited to surfaces that are highly smooth but not reflective.

- This review article on PL provides detailed information about potential PL uses in food processing (Mandal et al., 2020)
- *Listeria* may be able to develop tolerance to pulsed light (Heinrich et al., 2016)
- This article is basically an advertisement for one company (XENON) that is currently selling pulsed light products to the food industry. They market a product for conveyor decontamination as well as other products.

Visible light/LEDs and photodynamic inactivation of pathogens.

Visible light inactivation of pathogens is also sometimes called photodynamic inactivation; it requires visible light, usually in the 400 to 430 nm wavelength region (which is near the UV region but may be called "blue") and a photosensitizer. The photosensitizer can a molecule found inside the cell such as porphyrin; in the presence of oxygen in the cell, absorption of visible light excites these molecules which can lead to the production of reactive oxygen species which can react with DNA, lipids, and proteins, resulting in bacterial cell death (Kim et al., 2017). The photosensitizer can also be an exogenous chemical such as curcumin, riboflavin, etc. Blue light (405 nm) emitting diodes have been touted as a way to decontaminate food processing facilities, and commercial products appear to be available.

- Blue light w/o an added photosensitizer
    - Hadi (2020) is a thorough and recent review on blue light inactivation of pathogens in food processing applications. Table 1 provides information on studies of blue light inactivation of pathogenic bacteria on surfaces (Hadi et al., 2020).
    - Ghate (2019) is also a very detailed review and also presents a table (Table 1 that shows the activity of photodynamic inactivation of foodborne bacteria (Ghate et al., 2019). It provides a lot of detail about applications to food contact surfaces (Table 5 and information in text).
    - This older paper (Ghate et al., 2013) looked at the antibacterial effects of LED visible light at various wavelengths (461, 521, and 642 nm) on suspensions of *E. coli* O157:H7, *Salmonella, Listeria*, and *S. aureus* at different temperatures. The light at 461 nm (which is in the blue region) was most effective. No different in sensitivity between Gram-positive or Gram-negative organisms was seen.
    - 405 nm light appears effective against dairy-sourced *Cronobacter sakazakii*, especially when combined with hydrogen peroxide (Wu et al., 2021b). The study also tested sublethal hydrogen peroxide with blue light on 3-day old skim milk biofilms on stainless steel or plastic and found it able to effective in activating different *Cronobacter* strains.
    - *L. monocytogenes* biofilms on stainless steel or aluminum plates could be inactivated with blue light (405 nm) (Puranen et al., 2021). The addition of a titanium oxide nanocoating to the steel plate did not enhance the antimicrobial activity of the light itself (Puranen et al., 2021), although it did enhance microbial inactivation on the aluminum surface.

    - Blue LED light (405 nm) was able to inactivate 7 different STEC strain in vitro. Inactivation was time/light dose-dependent and was more effective on minimal or LB agar than on cooked meat agar or sheep blood agar (Wu et al., 2021a)
    - Blue LED light (405 nm) was able to inactivate *E. coli* O157:H7, *Salmonella*, and nonpathogenic bacteria inoculated on the surface of almonds (Lacombe et al., 2016)
    - According to literature from one company (Neu-Tech Energy Solutions, which sells blue light products for medical and non-food applications), blue light is able kill many Gram-negative and Gram-positive bacteria, bacterial endospores, yeast, molds, and fungi. Specific organisms that have been tested include *Salmonella*, *Listeria*, *Staphylococcus* spp., *Bacillus cereus* (spores and bacteria). Most of the studies cited by the company appear to be done on cells in media, although a few were on bacteria attached as biofilms on surfaces.
    - Here are more links on blue light related to food processing:
        - https://www.foodprocessing.com.au/content/food-design-research/article/chemical-free-food-preservation-using-blue-light-1424016779
        - https://turnontheblue.com/how-does-blue-light-kill-bacteria/listeria-and-salmonella-in-food-processing-plants/
- Blue light with added photosensitizer
    - (Cossu et al., 2021) reviews photodynamic inactivation (uses light such as blue LED light to activate an antimicrobial chemical) applied to food decontamination; the paper focuses more on using these technologies on food itself, but there may be some applicability to food contact surfaces, etc.
    - Use of photoactivated curcumin using a 465 nm LED light source to decontaminate food surfaces is discussed in one paper (Aurum and Loc Thai, 2019).
    - Blue light LEDs plus photosensitizers plus antimicrobials was shown to inactivate *E. coli* O157:H7 on fresh-cut apples and cherry tomatoes (Jeong-Eun et al., 2022).

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