White Paper

Recent Advances in Food Safety: The Power and Versatility of UVC Technology

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September 20, 2022

Any assessment of food safety and security today begins with a sobering statistic: In 2020, the World Health Organization (WHO) estimated that 600 million people, almost one in 10 worldwide, get sick each year from foodborne and waterborne microbes and pathogens (bacteria, fungi, molds, cysts, parasites and viruses). Of those afflicted, approximately 420,000 will succumb and die… and one third of those deaths are children. [1]

In the US alone, the Centers for Disease Control and Prevention (CDC) estimates that 1 in 6 Americans (48 million individuals) get sick annually from consuming food, beverages and water contaminated with known pathogens and 'unspecified agents' (unidentified microbes, chemicals, or other substances). Of these 48 million, 128,000 typically require hospitalization, and an estimated 3,000 die -- in many cases from preventable foodborne illness. [2]

From an economic standpoint, the US Department of Agriculture (USDA) Economic Research Service (ERS) estimated that the 15 most prevalent foodborne pathogens, which account for 95% of all cases, had up to $18 billion impact on the US economy in 2018. Consequently, reducing microbial contamination would not only improve and protect public health, increase food security and reduce food waste, but it would also help alleviate associated economic burdens.[3]

Fortunately, one of the best, most effective ways to help prevent many pathogen-related foodborne and food-prep illnesses is through the application of UVC (ultraviolet-C) irradiation – a proven, non-thermal disinfection method that does not alter the taste or texture, nor reduce the nutritional value, of food or beverages. And because there are so many different methods for generating and safely delivering UVC, this technology offers a remarkably broad array of options for any integrated cleaning and disinfection program.[4]

Overview of UVC for Food Safety

For decades, UVC has been an established, dependable technology used in the microbial disinfection of water, beverages, food solids, fruits and vegetables. From initial food processing, to greenhouses and warehouses, to cold chain distribution, UVC has long been recognized for its capacity to sterilize food packaging, extend shelf life (e.g., meats, blueberries), and even to enhance a food's nutritional value (e.g., mushrooms). In addition, more recent advances and new research indicate that some combinations of generated UVC (such as that from KrCl excimer lamps coupled with LED UVC emitters, or multiple wavelength LED treatment, or excimer lamps with mild heating) actually provide a synergistic gain in disinfection. And most notably, in some cases newly available LEDs and excimer UVC sources may prove superior to low-pressure mercury lamps (LP Hg) for enhanced bactericidal effect.[5, 6]

Commercially available UVC technologies offer food processors and food-prep providers a really wide, versatile range of effective high-performance solutions… providing improved economy, energy efficiency, enhanced scalability, and environmental responsibility.

Accordingly, when designing any new food safety program, it might well be prudent to consider all available and emerging UVC technologies to determine best practices, best fit, and the best long-term combination of emission sources to optimize your disinfection program

Foodborne and Food-Prep Resultant Pathogens

There are 31 known pathogens that cause most waterborne and foodborne illness outbreaks, including *Escherichia coli* O157:H7*, Salmonella Typhimurium, Listeria monocytogenes, Campylobacter,* and the more recently publicized, Noroviruses. Even the slightest contamination with some of these pathogens, like the Shiga toxin-producing *E. coli* O157: H7, can be absolutely devastating. One recent study indicates that as few as ten viable bacteria can cause disease in humans and can potentially lead to an overwhelming result.[7]

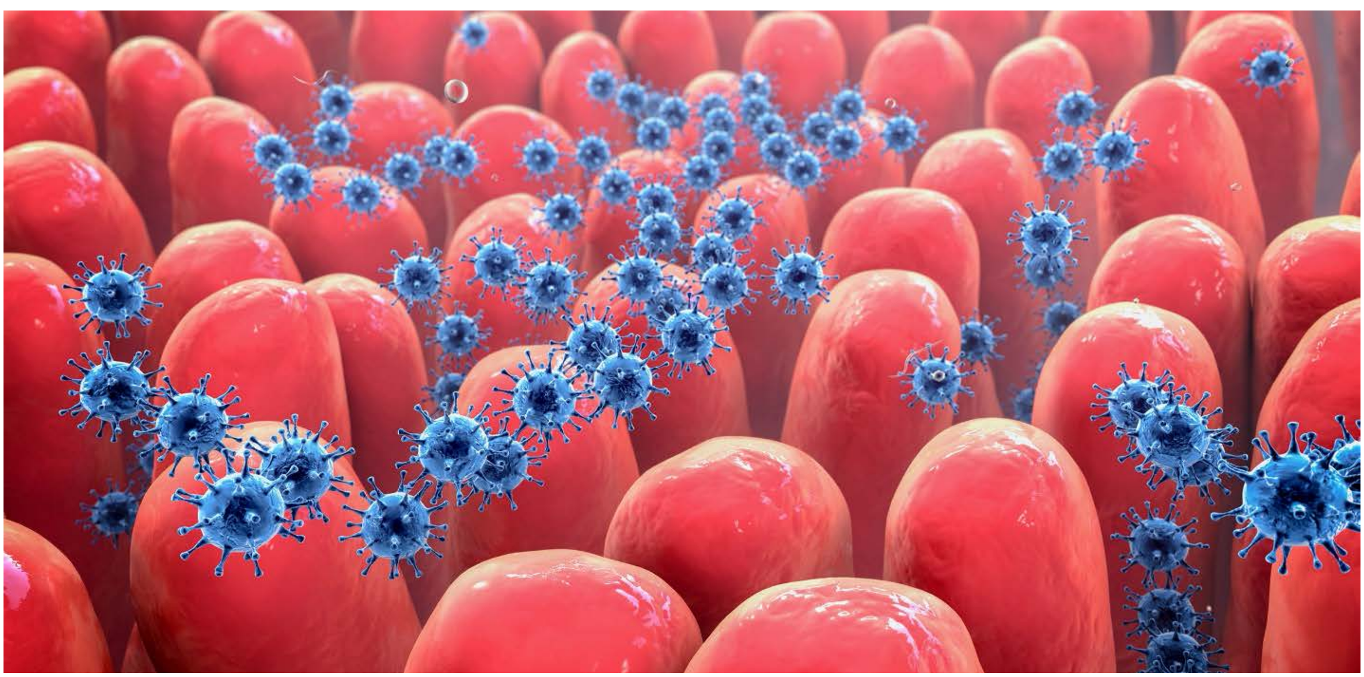


Figure 1: Artist rendering of viruses in human intestine. Viral enteric infection.

Because of highly publicized cruise ship outbreaks, noroviruses have recently gained notable worldwide attention. In reality however, noroviruses are already the leading cause of gastroenteritis around the world, with over 21 million cases annually in the United States alone. Noroviruses currently account for over 200,000 deaths globally per year. Much like *E. coli*, noroviruses are extremely contagious, and new research indicates that as few as 5 to 20 virus particles can lead to serious infection.[8]

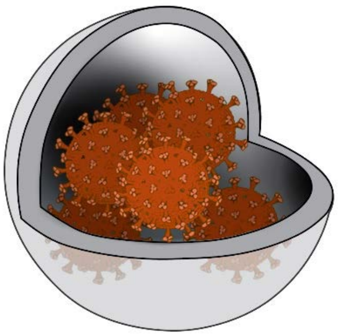


Figure 2: Rendering of multiple virus particles within a vesicle.

Complicating this further, noroviruses have been found to be somewhat resistant to chemical cleaning and UV_{254} disinfection (the typical 254 nm output from conventional, low-pressure mercury lamps). This is due in part because they are often encased in a protective and resistant outer shell, creating what are known as "vesicle-cloaked virus clusters" (viral vesicles, see Figure 2). These are phospholipid-bilayer, encapsulated fluid sacs that contain *multiple* viral particles.[ibid]

This is a fairly recent advance in our understanding of some of the most prevalent pathogens. And, while chemical cleaning and UV_{254} disinfection may not be totally effective, current research has indicated that coupling UV_{222} disinfection using krypton-chlorine exilamps in combination with other UVC emitters may indeed deliver superior inactivation of certain foodborne pathogens.

Excimer UVC irradiation may also have an additional advantage over low-pressure mercury sources in food safety for another very intriguing reason: Unlike UV_{254} from low-pressure mercury, UV_{222} from a KrCl excimer lamp is highly absorbed by both the pathogen's DNA and its outer membrane proteins (the outer membrane of all Gram-negative bacteria and most viruses contain protein). In this way, the UV_{222} generated by an excimer lamp ensures a *dual* deactivation impact. Compared to UV_{254} from a typical low-pressure mercury source, this double hit of DNA damage and protein interaction may increase the effectiveness of excimer-generated UV_{222} against some microbes. Although further research is needed, some recent studies support this comparison of KrCl excimer lamps with LP Hg lamps in the deactivation of *E. coli* O157: H7.[9]

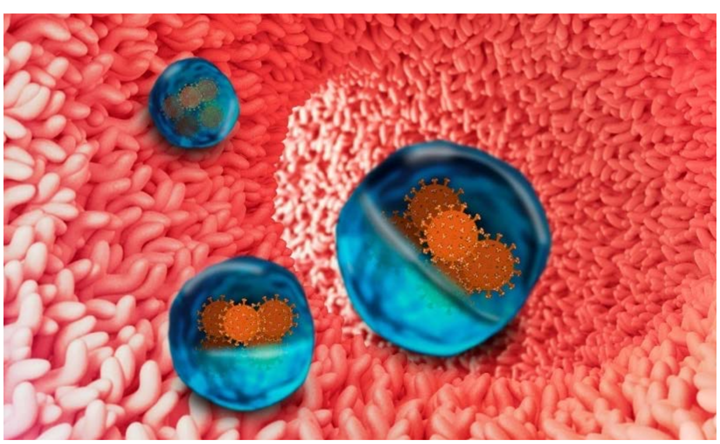


Figure 3: Rendering of multiple virus vesicles within a digestive tract.

Various UVC-Generating Technologies for Food Safety

The application of UVC in the food processing and food-prep industries has provided enormous benefits for decades. UVC radiation (200–280 nm) has excellent germicidal properties to deactivate a broad range of microbial pathogens (bacteria, fungi, yeasts, molds, and viruses). In food processing applications, UVC is unparalleled as a non-thermal, non-contact, non-chemical, non-ionizing method for pathogen control and deactivation.

UVC technology can be used to effectively lessen or eliminate transmission of foodborne pathogens, while simultaneously increasing the shelf life, and in some cases improving the nutritional content of food. UVC achieves this mainly by reducing microbial load, and it does so without compromising the food's quality. However, like any disinfection method, UVC processing of food depends on a variety of factors such as the operational parameters of the equipment, the immediate environment, microbial characteristics, and food composition.

That's exactly what makes UVC so ideal in the food processing, packaging and distribution chain: UVC can be safely generated by a number of technologies (LEDs, excimer lamps, pulsed xenon). Each of these methods has a unique set of strengths and advantages that can make it an exquisitely precise fit for a particular application (e.g. the requirements of conveyor disinfection can be quite different from the demands of clear beverage processing). This broad array of available UVC modalities enables the food safety engineer to design and develop a very targeted, comprehensive program throughout the process: The right tool for the right application.

The following review outlines the fundamentals and features of various UVC sources to inactivate pathogenic microbes for decontamination of foods and beverages like fruit and vegetable juices, milk and dairy products, meat products, beef, and seafood.

But first, a word about **hurdle technology**: In food safety, "hurdle technology" refers to an integrated or synergistic combination approach to ensure safe, stable and nutritious foods. The concept is quite established, and it relates to the "hurdles" that can be placed ahead of a pathogen to prevent it from establishing an infectious foothold. In this context, although a single preservation or decontamination factor (the hurdle) may be used to ensure food safety, current research has demonstrated that UVC technologies work particularly well in combination with each other (creating a more effective hurdle) to enable maximum food decontamination with minimal processing, and without compromising the food's taste or quality.

Low- and Medium-Pressure Mercury Lamps

One of the older, more common approaches in generating UVC radiation is through low-pressure mercury lamps (LP Hg). In terms of geometry, electrical connections and operating power, these lamps share much in common with standard fluorescent lamps without the coating. Emitting at 254 nm, low-pressure mercury lamps are constrained by longer warmup requirements, shorter effective lamp life, and the potential to deliver sublethal irradiation which allows the pathogen to repair and reactivate.

Medium-pressure mercury lamps (MP Hg) have also historically been used, particularly in water disinfection. Medium-pressure UV lamps are shorter in length than low-pressure lamps and emit a wider disinfection wavelength, 200-320 nm versus the 254 nm emitted by monochromatic low-pressure lamps. For UV germicidal or disinfection systems, this is an advantage since the broader spectrum damages the pathogen's proteins and enzymes as well as DNA. However, both are being phased out of new designs in favor of more environmentally responsible and energy efficient products.

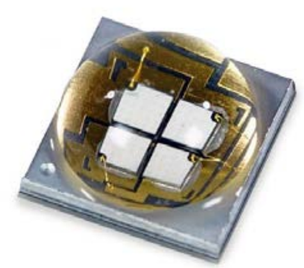
Furthermore, in 2013, the United Nations Environment Programme adopted the Minamata Convention on Mercury, which prohibits trade in mercury-containing products in order to protect human health and the environment. Effectuated in 2020, the use of low-pressure mercury lamps will eventually be discontinued, and new UV sources will replace the older, outdated technology.

Solid State Solutions (LEDs)

As one class of UVC emission sources, LEDs offer some very compelling advantages over low- and medium-pressure mercury in food, water and beverage processing.

For industrial water treatment, UVC LED systems provide instant on/off and dynamic switching capabilities, allowing for immediate adjustment to any change in operating conditions. UVC LEDs are also environmentally advantageous, as they eliminate the need for glass traps downstream while reducing costs associated with regulated waste disposal. In addition, some water utilities managers have been reporting significant reductions in power and chemical consumption after switching from mercury lamp systems to UVC LEDs.

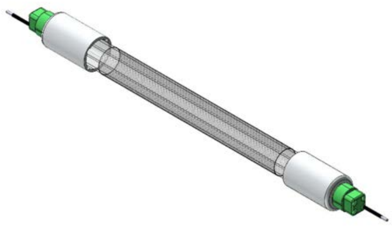
For food processing applications, most common UVC LEDs emit in wavelengths of 265 nm, 273 nm, 277nm, and 280 nm. This is a an enormous benefit since some pathogens exhibit a key sensitivity to particular wavelengths in combination.[10] As one example, it has been shown that some strains of *Listeria* and *E. coli* are more sensitive to UV treatment at 259 and 289 nm applied **simultaneously** compared with either wavelength applied alone. [11] This increases the previously mentioned *hurdle effect* due to the specific wavelengths damaging different metabolic structures, compounding and amplifying the stress on the pathogen.



LEDs have also shown very promising results for extending shelf life. Studies have demonstrated that UVC LEDs can simultaneously extend the shelf life of fresh produce, kill pathogens and minimize losses. For example, scientists at the USDA tested UV LEDs in the range of 285 to 305 nm to extend the shelf life of fresh fruits and vegetables in domestic refrigerators. Shelf life was doubled using 20 mW/m^2 of output power. This has been further supported by Allende et. al., showing that UVC LEDs routinely reduce natural microflora on lettuce leaves, thereby extending shelf life.[12]

Pulsed Ultraviolet Light (PUV)

Pulsed xenon, also known as pulsed ultraviolet (PUV) light, is an established, FDA-approved technology that has enormous applicability as an antimicrobial intervention in food processing. PUV is a non-chemical, non-aqueous, nonthermal (with short exposure), and non-ionizing technology. Numerous examples demonstrate the effectiveness of pulsed xenon for surface decontamination in the food industry. PUV technology offers a very wide range of form-factors and lamp output options, making this technology ideal when line-speed and processing throughput are critical.



Excimer Sources – Lamps & Systems

Excimer sources have recently emerged as an intriguing, effective tool for food safety. The 222 nm-emitting KrCl lamps provide a dual-approach to pathogen deactivation and have shown a synergistic effect when coupled with other technologies.[13, 14]

Excimer lamp sources can be used in certain retrofits with existing technologies to boost the effectiveness of UVC pathogen control, and they can easily be coupled with LED technologies to provide broad-spectrum protection.

Conclusions

Regardless of the food being processed or the pathogens of primary concern, UVC technology offers an extremely broad array of options and design features for effective disinfection. Emerging, environmentally responsible technologies like excimer lamps and LEDs provide enhanced protection from deadly pathogens and can work together to create a synergistic gain in protection. Pulsed xenon delivers a high throughput solution for conveyers, decontamination of shipping containers, and many other food processing applications. These emerging technologies are often more effective, more versatile, and more energy and resource efficient than any conventional mercury-based options.

Depending on the UVC emission source, the mechanisms of decontamination can also be two-fold: The primary mechanism of disinfection is via formation of photochemical lesions on DNA and RNA structures in the bacteria or virus. Basically, the UVC-induced damage results from the dimerization of pyrimidine molecules, thereby incapacitating the pathogen's ability to replicate. However in some cases, emission sources like excimer lamps may add a secondary inactivation mechanism – by damaging a virus's outer protein coating or a bacteria's cell membrane. This dual hit helps prevent reactivation or repair, which can sometimes happen with low-pressure mercury. The secondary mechanism may become a key advantage and can be a compelling rationale for incorporating tailored LEDs and KrCl excimer lamps into your complete disinfection program.

From farm to fork, UVC technologies have advanced considerably in recent years to create a very robust matrix of adaptable options. To meet today's challenges, any integrated, comprehensive food safety program should begin with a complete engineering review of newly available UVC technologies, along with an evaluation of your overall disinfection goals.

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