WHITEPAPER

Point-of-Use Water Disinfection

CONFIDENTIAL MATERIAL

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Our natural environment contains numerous microorganisms. Even in North America, where the water supply is among the safest in the world, the drinking water can become contaminated at the source, along the pipeline, or inside the drinking container, causing sickness and disease from waterborne germs, such as *Cryptosporidium*, *E. coli*, *Hepatitis A*, *Giardia*, and other pathogens. Point-of-use disinfection is an important step to ensure that water is safe to drink. This article describes various point-of-use disinfection methods and the advantages and disadvantages associated with each technique. In detail, point-of-use disinfection through adding chemical (chlorine and ozone in particular), filtration, and ultraviolet (UV) radiation are explained. Finally, the merits of ultraviolet light emitting diodes (UV-LEDs), as a new eco-friendly source of UV are discussed.

Introduction

While that sip of water has always been regarded as a life savior and essential to survival; today, we should be concerned about contamination that can render it detrimental to our health. "***Is it enough to just have a continuous supply of water?***" The answer is NO. It is not about the availability of water alone, but safety of drinking water is what we need to strive for.

Figure 1: Contaminated Water Facts.

Many people consider that is clear in appearance to be clean or safe for consumption. Unfortunately, this isn't always the case! ***Clear looking water is likely to contain harmful pathogens***, such as bacteria and viruses, if it is not well-treated via water disinfection processes.

Figure 2: Clear Water is Not Necessarily Safe.

Water disinfection process reduces or eliminates illnesses acquired through drinking water. An effective point-of-use water disinfection system, based on the U.S. Environmental Protection Agency (EPA) regulations, must reduce the population of *Giardia lamblia* cysts and enteric viruses by 99.9% [1]. The application of water disinfection methods is defined by their effectiveness in reducing the number of micro-organisms to the safe level.

Point-of-Use Water Disinfection

Municipal water supplies usually contain a safe level of micro-organisms. However, **harmful contamination may have occurred during the transportation and storage of water**. Moreover, for some people such as recreational enthusiasts, military personnel, and survivalists, who need to obtain drinking water from untreated sources (e.g. rivers, lakes, groundwater etc.), it is vital to disinfect water at the point-of-use (PoU). Thus, point-of-use water disinfection applications (single-faucet household, boats, RV, etc.), have attracted tremendous attention in the recent years.

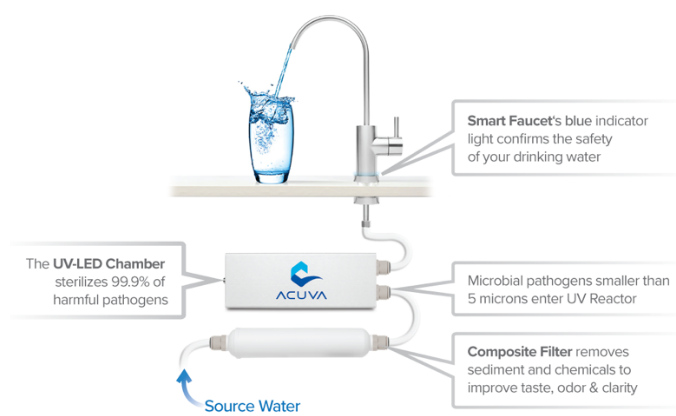

Figure 3: Example of a Point-of-Use (PoU) Water Disinfection System

Boiling of water is an effective method for excluding micro-organisms from water, yet it cannot be used as a permanent approach, as it is inconvenient and costly. Current common user-based water disinfection methods are:

1) Chemical disinfection,
2) Filtration, and
3) Ultraviolet disinfection

Figure 4: Current Common User-Based Water Disinfection Methods – Boiling, Chemical, Filtration, UV Disinfection.

Chemical Disinfection

At the municipal level, chemical disinfection is the most common method to combat micro-organisms in water. Chemical disinfection uses strong oxidants, such as chlorine-based compounds and ozone, to rapidly react and kill harmful micro-organisms.

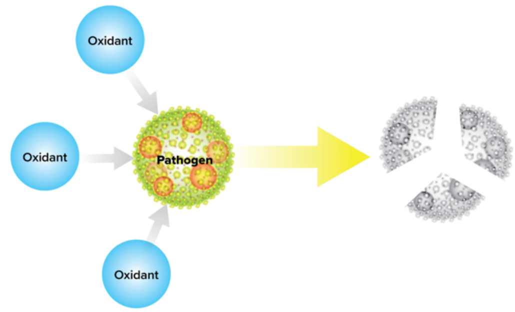

Figure 5: Chemical Disinfection of Water Using Oxidants.

Chlorine

Adding chlorine in the form of gas, liquid (sodium hypochlorite solution [2]), or solid (calcium hypochlorite [3]), the so-called chlorination, has been practiced for decades as a convenient water disinfection technique for water storage systems and swimming pools. Chlorine-based compounds have also been used as disinfectant tablets for household and outdoor applications [4].

Advantages of Chlorine

- Chlorine is fast and effective for water disinfection [5]
- It helps with secondary disinfection (residual effect), as the oxidants stay in the water to prevent future contamination in plumbing system and during storage [6]

Disadvantages of Chlorine

- Health concerns:
  - ↳ Chlorine gas is extremely dangerous, where USEPA has established a chronic reference exposure level of 0.00006 mg/m^3 [7]
  - ↳ It generates harmful disinfection by-products, such as trihalomethanes (THMs) [8]
  - ↳ It is not capable of removing all harmful cysts and viruses [9]
- Safety concerns:
  - ↳ Chlorine-based components are very corrosive, so must be handled with extreme care [10]
  - ↳ They must be stored in dark, cool and dry conditions [11]
- Chlorine-based compounds change the odor and taste of water [12].

Ozone

Ozone is an unstable gas comprising of three oxygen atoms, which readily degrades back to oxygen and during this transition a free oxygen atom or free radical forms. The free oxygen radical is highly short lived and oxidizes micro-organisms and chemical compounds.

Advantages of Ozone

- Ozone has stronger germicidal properties then chlorination. Ozone also offers fast oxidization of some chemicals [13]
- Ozone treatment does not require on-site storage, as can be generated in-site
- Water ozonation promotes the flocculation/coagulation process [14], which reduces treatment cost and time in larger scales

Disadvantages of Ozone

- Effectiveness for PoU
  - ↳ If the concentration of ozone is too low, some of the germs and especially those that can form cysts may survive [15].
  - ↳ Ozone is unstable and its concentration in water drops rapidly [16]; thus, the disinfection cannot be sustained (no residual effect). Such characteristics lead to growth of microorganisms in the downstream plumbing system and during storage.
  - ↳ Some ozone degraded organic molecules will promote bacteria growth [17].
  - ↳ Ozone disinfection requires certain contact time [18]; thus, it cannot be used as flow-through point-of-use systems.
- Health Concerns
  - ↳ There are evidences suggesting the adverse effect of ozone on respiratory systems [19], it is important that it is completely degraded before it reaches the point-of-use.
  - ↳ Inorganic compounds are oxidized by ozone, flocculate, and create deposits that should be filtered out after the tank [14].
  - ↳ By-products of organics in water and ozone are not fully known and sometimes harmful to human [20]. For example, Bromide contamination is common, where the by-products of its reaction with ozone is known to be human carcinogen [21]. Due to this uncertainty, water ozonation is banned in some regions with bromide contamination [22].
  - ↳ Ozone indoors include those produced by ozone generators, decreases in pulmonary function and increases in subjective respiratory symptoms. Health Canada limited ozone exposure to less than 20 ppb for a period of 8 hours [23].

- Maintenance
  - Ozone generators require periodic service and maintenance [according to several ozone generator's manufacturer].
  - Ozone is a reactive compound and at a certain concentration reacts with alloys such as fittings, valves and faucets [24 and 25].

Other Chemicals

Several chemicals such as iodine crystal [26] and silver ion [27] compounds are used in the form of solution, powder, or tablet for point-of-use applications. Despite their low cost and convenience, frequent use of strong oxidants is prohibited particularly when the storage container is not well-mixed or the required time for dissolution and disinfection of the chemicals are not given. In addition, any chemical disinfection demands active operation and attention and requires appropriate settings for chemical storage and delivery.

Filtration

As one of the simplest types of point-of-use treatment, filters trap particles in a porous material structure; while allowing water to pass through. Basic filters can reduce particles like sand and rust but cannot remove anything dissolved in the water. Filter devices are relatively inexpensive and reported to be effective for point-of use disinfection applications [28], but require regular maintenance, which adds to the cost. Membranes are also considered as filters, since particles larger than the membrane's pores can be removed from water stream. The most popular filtration devices that eliminate micro-organisms are reverse-osmosis (RO) devices and advanced ceramic filters.

Advantages of Filtration

- Filtration can be designed to remove specific micro-organism, owing to recent advances in material science [29]
- Filters are capable to provide high flow rate
- Basic filtration systems re relatively inexpensive

Disadvantages of Filtration

- Filtration system pose high maintenance cost (frequent replacement of cartridges)
- At smaller pore size (higher purity), pressure drop is considerable, and lifetime is shorter
- Micro-organisms are not killed, but trapped, so there is chance of secondary contamination [30]
- Many viruses cannot be removed from water via filtration, as the pore size of even the most advanced ceramic filters (about 1 micron) is considerably larger than the size of many viruses (less than 0.1 micron) [31]

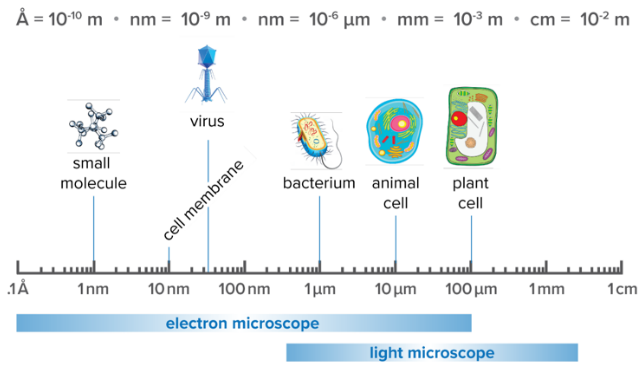

Figure 6: Size of Micro-Organisms.

- RO systems are expensive, hard to install, and waste as much as 70% of the water that is being treated [32]

UV Disinfection

UV disinfection utilizes strong short-wavelength (250–280 nm) radiation to inactivate microorganisms by destroying the nucleic acids and disrupting their DNA, leaving them unable to perform vital cellular functions [33]. Currently, many major cities in Canada, United States, and Europe, such as Vancouver, New York, and Paris have adopted UV as their primary water disinfection process, making UV one of the fastest growing water treatment technologies.

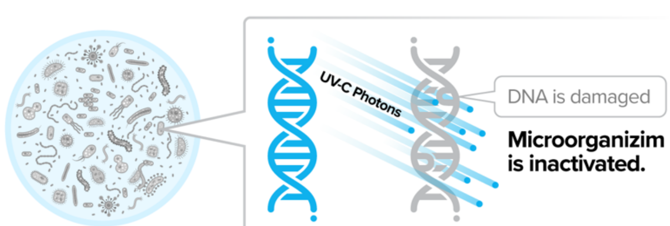

Figure 7: The Principle of UV Disinfection.

Advantages of UV Disinfection

- UV radiation is the most effective method to eliminate pathogens. For example, Cryptosporidium and Giardia are resistance to chemical disinfectants; however, with mild UV radiation they can be safely eliminated by 99.99% from water [34].
- UV disinfections adds no by-product and/or secondary contamination to water, which is idea for laboratory and medical applications where unknown by-products are undesired.
- Unlike conventional reverse osmosis systems, UV disinfections does not waste any water as disinfection occurs while water flows through the disinfection device.
- UV radiation sources have considerably longer lifetime (typically over 8,000 hours), compared to other disinfection methods [35]
- UV disinfection devices have low maintenance, annual inspection is sufficient
- UV disinfection does not change water’s taste and odor

UV-lamp vs UV-LEDs

The conventional technique for UV water treatment utilizes low and medium pressure UV mercury lamps, where the UV radiation is generated through mercury excitation. However, there are serious environmental and performance concerns related to UV-lamps based water treatment.

Disadvantages of UV-lamps

- Mercury-content of the lamps that raise a serious environmental concern [36]
- Solubility of majority of inorganic compounds in water is a function of temperature [37]. The high temperature of lamps surface and protective quartz sleeve causes scaling of these compounds (reduction in performance) and raise in water temperature [
- High operating power and voltage requirement
- Inability to frequently turn them on/off, meaning the lamp is on and drawing power even when there is no water flow. Such operation setting results in shorter lifetime (typically one year) and high maintenance cost [36]
- Bulky design of the UV-lamps limits the reactor's design and efficiency

These limitations in UV water disinfection systems can be addressed by replacing UV-lamps based reactors with those designed with UV-Light Emitting Diodes (UV-LEDs).

Point-of-Use UV-LED Water Disinfection

As a recent scientific accomplishment, UV LEDs are considered as a revolutionary technology, and the future of lighting and optics. UV LEDs operate at low energy and generate UV radiation at sharp emission spectra and tailored peak wavelength, that targets maximum absorption of micro-organism DNA [33 and 36]. These characteristics enables UV LEDs to enhance the pathogens disinfection efficiency significantly, compared to conventional UV lamps.

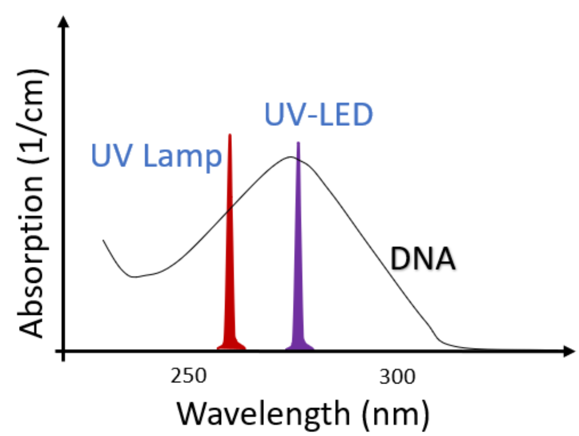

Figure 8: Comparison of UV-LED and UV-lamp Emission Spectra.

Advantages of UV LEDs

- Can operate on instant on/off mode, saving considerable amount of energy and expand lifetime significantly [36]
- Contain no hazardous materials [33 and 36]
- The characteristics of the radiation (such as wavelength) can be adjusted in accordance to those required for inactivation of micro-organisms [38]
- Enhances UV reactor design flexibilities, thus the water disinfection efficiency increases

Table 1: Comparison of UV-lamps and UV-LEDs.

	UV Lamps	UV LEDs
Instant On/Off	No	Yes
Warm-up Time	2-7 min	Zero
Operating Power/Voltage	High	Low
Environmental /Disposal Hazard	Yes (mercury content)	No

LED technology allows UV water treatment to be used in applications that are unavailable to conventional mercury lamps. For example, devices based on UV-LEDs can now be integrated into PoU appliances and laboratory equipment and water dispensers, where DC voltage operation and small foot-print are needed. Also, UV-LED devices enable the supply of drinking safe water to remote communities, and the developing countries, where access to all-day-long electricity is a challenge. In such cases, UV-LED devices can operate with DC voltage sources such as batteries or solar cells. In addition, the small dimension, low weight, and flexible design provides the opportunity to use UV-LEDs in portable water purification systems, appliances, and PoU devices.

Conclusion and Remarks

Point-of-use water disinfection has received tremendous attention in the recent years. This article described various disinfection systems and explored the advantages and drawbacks for point-of-use water applications. It is discussed that UV radiation possess significant advantages for flow-through point-of-use application, in particular when it is combined with sediment filters. In particular, UV-LEDs were applied to batch and flow-through water disinfection systems and demonstrated an outstanding performance. This article summarized some such characteristics.

The Table 2 summarizes the features of different disinfection methods that has been described in this paper.

Table 2: Comparison of Water Disinfection Methods.

	Effectiveness	Good Taste	Easy to Install	Compact	Low-Maintenance	Eco-Friendly
UV-LEDs	✓	✓	✓	✓	✓	✓
Filters		✓	✓	✓	✓	
UV-Lamps	✓	✓				
Chemical	✓		✓	✓		
RO	✓					

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