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Decontamination of Treated Wastewater By means of a Modern Ultraviolet LED Reactor System

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ABSTRACT

Poor sanitation systems have been a significant contributor to high death rates in many low-income countries since they tend to promote the spread of waterborne diseases. Both the public and commercial sectors have a strong interest in developing and upgrading the health systems in these countries. Chemical oxidants that are commonly used (e.g., chlorine) signify the method most commonly used to disinfect wastewater due to some practical rewards. Nevertheless, a lot of evidence shows that harmful by-products of disinfection (DBPs) have a direct link to DBP generation. This research investigates the use of UV-LEDs to sterilize the secondary household sewage treatment system. Though UV-LED treatment has grown in popularity recently, it is still a cutting-edge method for treating domestic sewage. Domestic sewage was pretreated via an affordable pretreatment structure containing a settler inclined at an angle and a sand-medium screen before being fed into a novel flow-through ultraviolet LED reactor. Reusing processed wastewater from treatment plants that use UV-based combination processes shows outstanding potential due to a negligible impact on the environment relative to disinfection byproducts generation and effective microorganism-based disinfection at high yields, but more research is needed to confirm this (more than a three-log reduction is typical).

Keywords: Ultraviolet, Light Emitting Diode, Wastewater, Sewage, Ultraviolet light emitting diode, UV radiation, Disinfection byproducts

Abbreviations: UV – Ultraviolet, LED – Light Emitting Diode, DBPs - Disinfection byproducts, WW - Wastewater

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1. INTRODUCTION

According to a recent study, between 2011 and 2016, there were over 380 disease epidemics caused by aquatic habitat's protozoan parasites worldwide [1]. Additionally, South Asia and Countries in the Sub-Saharan accounted for 87 percent of all cases of global mortality linked to diarrhea [2]. The lack of clean water and proper sanitation facilities is a major factor in these general health issues [3]. Hence, in order to solve these problems, establishing decent sanitation systems particularly disinfection procedures, play a very important role.

One of the most popular and efficient treatments for water and wastewater purification is the ultraviolet (UV) disinfection. Although other common disinfection treatments, like ozone, chlorine oxide, chlorine, and peracetic acid, have also been widely employed, they all include chemicals and/or processes that produce chemical byproducts. Due to its non-corrosive nature and lack of disinfectant byproducts and residuals, UV disinfection is regarded as an environmentally acceptable treatment method. The ultraviolent treatment process has been studied for use in effluent reuse because of this [4]. From an investigation of Middle Eastern water recycling, an assessment of ultraviolet disinfection for the removal of enteric microbes that are sustained after disinfection by non-natural swamps was conducted [5]. Disinfection by ultraviolet treatment was successful in Southern Italy in the reduction of parasitic protozoa for unconstrained wastewater recycling from cities for agricultural purposes, giving no development of byproducts of the treatment process [4]. Additionally, UV disinfection has shown excellent effectiveness in Catarina, Brazil, during alkaline-controlled swine secondary waste treatment for water recycling [6].

These earlier researches utilized conventional mercury-vapor UV lamps, which when they break or discharge mercury vapor into the environment or air, threaten the health of people and the environment in a significant way [7]. Due to the mercury conference at Minamata, the United Nations Environment Program (UNEP) worked to reduce mercury waste and stop its release into the sea, soil, and atmosphere [8]. The conference promotes the use of mercury-free products by encouraging businesses and governments to embrace them, even if mercury ultraviolet lamps were not specifically addressed. Moreover, mercury ultraviolet (UV) lamps have a substantial carbon footprint, which is extremely delicate and sensitive to temperature changes.

Ultraviolet LEDs have been studied lately as a prospective unique source of ultraviolet radiation, giving benefits that potentially outweigh the drawbacks of conventional lamps, such as long life, strong structure, low power consumption, and no mercury use, have been one such option [9, 10]. The ultraviolet C light emitting diode is the most energetic of the three varieties of ultraviolet LEDs. Additionally, UV-C LEDs exhibit the shortest wavelength. The more damaging ultraviolet light is dependent on the shorter its wavelength, so the energy of UVC rays is the greatest in the UV spectrum. Since UV-C has the shortest wavelength and is therefore the most destructive, it does not pose a significant threat to the average person. When a planet's atmosphere is thick enough, ultraviolet rays don't even have a chance to penetrate it. The ozone layer completely absorbs all ultraviolet light, which in no way discounts the risk posed by ultraviolet (UV) light.

Even while naturally occurring UV radiation is unable to make its way through Earth's atmosphere, there are inorganic sources of UV radiation that, if used incorrectly, might cause serious injury. Welding torches, mercury lamps, and germicidal UV lighting are all examples of artificial UV sources; therefore, workers using these should take precautions to protect themselves from overexposure to the sun's rays. In contrast, research on flow-through ultraviolet LED systems is scarce, and this is a major barrier to the widespread adoption of this technology for wastewater disinfection in real-world settings. The use of ultraviolet disinfection is not without its downsides. The effectiveness of the ultraviolet disinfection process can be reduced due to absorption, scattering, and the shielding effects caused by wastewater components such as sediments, acid from organic residue of decaying organic matter, and turbidity [11,12]. As a result, effective up-stream treatment procedures are frequently a key to success in UV disinfection applications.

Smith and Davis, in 2013 employed a low-cost, traditional process that included a sand medium for filtration and an angled tube settler in order to pre-treat the domestic wastewater before feeding it to the unique flow-through ultraviolet light-emitting diode reactor. It is the usual practice to utilize inclined settlers, which have a larger total settling area compared to other types of sedimentation, to increase the settling rates of clarifying processes, particularly when no chemical flocculation is present. Inclinations ranging from 8° to 60° have been used in inclined settler systems throughout the literature. However, many industries and manufacturers incline their products at 60^0 degrees as long as it lessens environmental Impact caused by the operations and guarantees the flow of sludge [13]. For removing a variety of physical, chemical, and biological pollutants, water and sewage treatment by slow sand filtration is a time-tested method that has been proven effective. Additionally, slow sand filtration techniques can also be utilized as a tertiary treatment in wastewater treatment facilities since they are low-priced, user-friendly, and low-maintenance. Sand grains typically range in size from 0.1 to several millimeters [14-16].

Implementing UV-LED disinfection technology also involves some maintenance obligations. Fouling is indeed a crucial factor to take into account when using UV disinfection methods. Due to a reduction in UV transmittance caused by the formation of foulant on quartz sleeves as a result of operating temperature increases, the UV dose delivered could be drastically reduced [17]. Light-emitting diodes have been theorized to be less susceptible to fouling than mercury-vapor lamps due to the fact that the LEDs' heat is dispersed in the opposite direction of the fixture, and as far as we are aware, there hasn't been any attempt to measure fouling when using an UV-LED disinfection procedure for wastewater treatment [18].

2. DISINFECTION OF TREATED SEWAGE

Traditional secondary and tertiary sewage treatment processes do not reliably produce microbiologically safe effluents that may be released into the environment or reused, despite significantly reducing the quantity of enteric bacteria. Using a disinfection treatment is necessary if we want to get rid of enteric germs effectively. Chemical and physical processes are used to remove bacteria and viruses from water. Usage of chemical disinfectants such as gaseous chlorine (Cl_2), chlorine dioxide (ClO_2), chloramines, ozone (O_3), sodium hypochlorite (NaOCl), calcium hypochlorite ($CaOCl_2$), and peracetic acid (PAA) are examples. UV irradiation is a widely used physical method for disinfecting water and sewage.

Considerations that may affect the effectiveness of disinfection

The concentration of disinfectant, disinfectant type, time of contact, the number and type of microbes in the water, as well as ecological factors including the quality of water, temperature, and pH, are the most crucial elements impacting the effectiveness of secondary sewage disinfection [19]. The features of the disinfectant employed have the greatest impact on how effectively it disinfects. Multiple disinfectants exist, each with its own unique disinfecting process and oxidizing properties. In most cases, the use of chemical disinfectants leads to the loss of selective membrane permeability in bacteria. The nucleic acids and enzymes of the bacteria could be damaged by the chemical disinfectants, rendering them incapable of replicating and of carrying out their metabolic processes. Nucleic acids and the viral protein coat may be harmed by chemical disinfectants [20]. Typically, an extended time of contact (t) between the disinfectant and the microbe and/or higher concentration disinfectant concentration (C) results in more effective disinfection.

The degree to which microorganisms are protected from disinfectants depends on a number of factors, including the microorganism's species, its age, and its physiological state. The following is a typical progression of increasing resistance: Protozoan cysts > spore-forming bacteria > vegetative bacteria > enteric viruses [19, 21]. Resistance of microbes differ, not just among types of microbes but also amid strains of the same types, and it also depends on factors such as age, diet, and general health [19]. In addition, the pH and temperature are also factors that affect the disinfection process [22]. Some chemical disinfectants in water take on different shapes depending on their pH, which can affect their disinfection effectiveness. Higher temperatures in general kill more microorganisms, and this is attributable to the effect of temperature on reaction rate. At lower temperatures, microbes may be less responsive to disinfectants because their metabolism is slowed [23].

The quality of the water used in the disinfection process can have a significant impact on how effective the process is. Chemical substances such as nitrogenous chemicals, iron, organic debris, and organic and inorganic nitrogenous mixtures impede disinfectant effectiveness. When organic compounds interact with a disinfectant, the rate at which microbiological agents are removed is slowed down, and harmful DBPs are produced, the demand for the disinfectant may increase. Microorganisms may be shielded from the disinfectant or ultraviolet radiation if suspended particles and organic materials are present [23]. Although the kinetics and mechanisms by which microorganisms are killed vary depending on the disinfectant used, the inactivation process of microorganisms can be defined using mathematical equations that consider the most important process variables, including environmental factors like pH and temperature, the concentration of disinfectant, time of contact, microbial number The eradication of microbes during the process of disinfection can be characterized using the general first-order expression below:

$$\frac{N_2}{N_1} = e^{-kt}$$

In the expression above, ‘k’ denotes the microbial decay constant while ‘N_1’ and ‘N_2’ denote the numbers of microbes existing at the beginning and end of the time. Deviations from this ideal behavior have been observed, and they are often attributed to the existence of bacteria that are resistant to disinfection treatment, or to the protection of microorganisms that are present before, during, or after the treatment, for example, within the particles or bacterial clumps in source water that need to be removed before the treatment process can begin [19, 20 & 24]. In or to better characterize the inactivation of germs by disinfectants; many mathematical models have been devised, including the Selleck's model, a new S-model, the Chick-Watson's model, and the Hom's model [25].

Disinfection process applicability

Under normal conditions of use, a perfect disinfection system would effectively and reliably eliminate all possible risks of microbial infections. The desired level of disinfection may be used as a criterion for selecting a disinfection method in light of the wide variation in disinfection efficacy among various disinfection strategies. Disinfecting secondary treated sewage effectively should not result in the formation of toxic, mutagenic, or carcinogenic disinfection by-products (DBPs) or sustained decontaminator deposits that could have negative impact on ecological or human wellbeing. The amount and type of disinfectant used, as well as the amount and type of biological substance in the water, affect how DBPs are made [26]. Disinfection process applicability evaluations should take into account factors such as the simplicity and adaptability of the process's operation and control, the low maintenance requirements of the devices used, and the safety of the disinfectant's handling, storage, and transport from an occupational and environmental standpoint. The cost of disinfecting should also be low, both at the beginning and over time.

Disinfection methods

- **Chlorination**

Chlorination is widely used as the secondary disinfection procedure for treated sewage. Since the turn of the twentieth century, chlorine disinfection has been widely used to reduce the prevalence of waterborne diseases all over the world [20]. Chlorine gas (Cl_2), hypochlorite of sodium (NaOCl) and calcium ($CaOCl_2$), and chloramines are just some of the chlorine compounds utilized for disinfection. Although NaOCl and $Ca(OCl)_2$ disinfectants cost more than the gaseous chlorine, their lower risk of injury makes them a top choice in smaller treatment facilities [27]. Chlorine gas and hypochlorite salts hydrolyze in water to produce the hypochlorous acid:

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$$

$$NaOCl + H_2O \rightarrow HOCl + Na^+ + OH^-$$

Hypochlorous acid dissociates further in water to form hypochlorite ion:

$$HOCl \rightarrow H^+ + OCl^-$$

Hypochlorous acid predominates in water at acidic and neutral pH levels while hypochlorite ion predominates at alkaline pH levels. Because hypochlorous acid disinfects more effectively than hypochlorite ion at acidic pH levels, chlorine disinfection is more effective overall [20].

Free accessible chlorine refers to chlorine in the form of OCl^- and HOCl. It is easy for HOCl to react with organic nitrogen molecules or ammonia in the water. A combination of chlorine (chloramines), chloro-organic compounds, and chloride are the byproducts of these non-specific side reactions. Disinfectants that contain chloro-organics or chloride are ineffective. The term "combined available chlorine" is used to describe chloramines. The initial chlorine to ammonia ratio in water, as well as the pH, temperature, contact time, and other factors, all influence the species distribution of chloramines [22]. When compared to combined chlorine, free chlorine is a disinfectant that is roughly 50-100 times more effective and significantly more reactive. Measuring the amount of free chlorine that remains after treatment is a common way to assess the effectiveness of chlorination [20, 22].

To achieve free chlorine residues in water, breakpoint chlorination can be used, which requires a sufficiently high chlorine dose to be added. Due to the high chlorine doses required, breakpoint chlorination is not commonly used in wastewater treatment. Therefore, monochloramine is the most predominant chlorine component found in wastewaters as chlorine typically exists in the combined form in wastewaters [28].

When it comes to killing germs, chlorine performs admirably against many types of enteric bacteria, but it's not nearly as effective against viruses, protozoan cysts, or bacterial spores [29]. The typical chlorine dose for wastewater effluent treatment is between 5 and 20mg/l [30]. In order to kill off more resilient bacteria like viruses, a higher chlorine concentration of 20–60 mg/l may be required [20]. Chlorine doses may need to be increased due to contaminants in wastewater which cause the significant chlorine demand [31]. When using chlorine for disinfection, contact periods typically range from 30 minutes to 2 hours [32].

Chlorination is a proven process with a long history of use in the disinfection of water and wastewater. In addition to oxidizing some organic and inorganic substances, chlorination can also be employed to get rid of some unpleasant odors. The application of chlorination for effluent treatment has been dwindling, despite the fact that it is a technically straightforward and adaptable process. The primary causes of this are toxic, mutagenic, and/or carcinogenic disinfection by-products (DBPs), an increase in the salinity of the effluents v chlorine residuals, and chlorine residuals [29, 33]. According to reports, changes in the time of contact, chlorine dose, pH, and temperature, all impact the creation of DBP whereas changes in the wastewater's organic carbon content and the ratio of ammonia to nitrogen are believed to have opposite effects [34]. Before wastewater effluent is typically discharged into natural waters, chlorine residues must typically be neutralized, otherwise it depletes dissolved oxygen in the water, it adds to the environmental problem of chemicals, and it increases the cost of disinfection [27, 30]. Being a very poisonous and corrosive compound, chlorine raises safety issues as well as environmental risks when it is handled, transported, and stored.

- **Chlorine dioxide (ClO_2)**

Chlorine dioxide (ClO_2) is an effective disinfectant in both potable water and wastewater, it has very strong oxidizing properties. Chlorine dioxide is as effective, if not more so, than chlorine at killing bacteria, viruses, and protozoan cysts [35, 36].

ClO_2 must be made locally or on-site using liquid or gaseous chlorine, sodium chlorite, hydrochloric acid, or by exposing sodium chlorite to ultraviolet radiation [37]. The generation ClO_2 is simple and cheap, but the expenses of using ClO_2 to disinfect water are more than that of using chlorination [36].

It is important to note that chlorine dioxide does not hydrolyze but it rather exists as a dissolved gas in water. There is no lingering effect from ClO_2. Chlorine dioxide has a mild reaction with compounds of nitrogen and organic matter in water, which inhibits the production of disinfectant byproducts. Chlorate (ClO_3^-) and chlorite (ClO_2^-) are inorganic byproducts of

ClO_2 that can be hazardous [36]. Some bacterial mutagenicity and toxicity, but no geno-toxicity, was seen after ClO_2 disinfection of secondary treated sewage [26].

- **Peracetic acid (PAA)**

PAA (CH_3COOOH) is a potent biological peroxyl molecule with strong oxidizing characteristics. There has been extensive use of PAA as a sterilant or disinfectant in many different settings, including research laboratories, the food processing industry, hospitals, and pharmaceutical factories. The reduction of pathogen in bio solids, slurry de-bulking, and odor elimination, disinfection of cooling towers and ion exchangers, are a few other applications. PAA has also been employed as a decoloring or disinfecting material in the pulp and paper industries as well as textile industries [38].

A commercially accessible form of peracetic acid is a quaternary balance combination comprising peracetic acid, acetic acid, stabilizers, water (H_2O), and hydrogen peroxide (H_2O_2).

$$CH_3COOH + H_2O_2 \rightarrow CH_3COOOH + H_2O$$

PAA dissociates in H_2O as described by the equations below [39]:

$$CH_3COOOH \rightarrow CH_3COOH + \tfrac{1}{2}\, O_2$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

$$H_2O_2 \rightarrow H_2O + \tfrac{1}{2}\, O_2$$

It was also determined that peracetic acid may be used up according to the following chemical reactions in the aqueous mixture [24]:

$$2CH_3COOOH \rightarrow 2CH_3COOH + O_2$$

$$CH_3COOOH + H_2O \rightarrow CH_3COOH + H_2O_2$$

$$CH_3COOOH + \text{Metal} \rightarrow O_2 + \text{other decomposition products}$$

Hydrolysis is extremely low and practically negligible between the pH range of 5.5 and 8.2. According to the second-order kinetics, the rate of spontaneous decomposition is proportional to the concentration of PAA. It has been hypothesized that the undissociated acid form of PAA, which predominates at pH levels below 8.2, is the biocidal active form [24]. PAA's effectiveness as a disinfectant is diminished above a pH of 8.2, as its rate of dissociation increases. The suggested mechanism of disinfection using peracetic acid includes the emission of active oxygen and the generation of microbe-killing hydroxyl radicals [39, 40]. Toxic or mutagenic DBPs or chemical residues are not significantly released into effluents during PAA disinfection [41]. However, it does not appear that all the chemical conversions performed by peracetic acid on the effluent matrix are well understood [23, 29].

Peracetic acid disinfection has been found to be a promising strategy for sanitizing wastewater in recent research. PAA has demonstrated effective disinfection against a wide variety of enteric bacteria in a variety of wastewaters, but it is less effective against viruses, bacterial spores, and protozoan cysts [42]. Easy installation and operation are two of PAA treatment's many benefits. High expenditures and an increase in the water's BOD/TOC concentration are two potential downsides of PAA treatment [38]. It has been shown that PAA-treated microbial populations can recover under specific circumstances [43]. There has been no detectable bacterial regrowth following PAA disinfection treatments, according to [33, 44].

- **Combined disinfection treatments**

Combining different disinfection procedures might increase the efficiency of the disinfection process or provide synergistic benefits. Because of this synergy, the combined decontamination strategy is more efficient than the sum of its individual effect. It was reported that synergistic inhibition of MS2 coliphage and Escherichia coli can be achieved with the use of chloramine and copper in the disinfection of well water [45]. Ozone and free chlorine work together well to kill Cryptosporidium parvum in natural water. The inactivation of MS2 coliphage was found to be enhanced by a combination of ultraviolet (UV) irradiation and silver in water, as reported by [46].

Disinfection methods that use advanced oxidation processes (AOPs) have come to the forefront in recent years. Many different types of organic contaminants found in polluted ground waters and industrial effluents can be effectively treated with AOPs [47]. AOPs oxidize organic contaminants through the use of potent oxidizing intermediates, most commonly hydroxyl (OH) radicals. The hydroxyl radicals can be produced in different methods, including the mixing of hydrogen peroxide and ozone, ultraviolet light and ozone, or hydrogen peroxide and ultraviolet light [47]. It has been found that the combined PAA/UV disinfection of wastewater effluents increases disinfection efficiency and has synergistic advantages [39]. To disinfect with TiO_2, E. coli inactivation was found to be linearly proportional to the concentration of hydroxyl radicals [48]. They determined that hydroxyl radical is 1,000 to 10,000 times more effective than common chemical disinfectants like chlorine and ozone at killing E. coli. To kill vegetative bacteria and bacteriophages, the ozone/hydrogen peroxide method has been shown to be effective, as described by [47].

- **Membrane filtration processes**

Recent years have seen a surge of interest in membrane separation procedures like ultrafiltration (UF), nano-filtration (NF), microfiltration (MF), and reverse osmosis (RO) for the enhanced disinfection of municipal wastewaters [49]. One major benefit of these procedures is that they effectively eliminate microorganisms without generating potentially dangerous DBPs. When using membrane procedures to remove microorganisms larger than the size of pore of the membrane, efficacy of separation is also affected by membrane fouling, pressure, and permeates flux [49]. Jolis in 2006, used a pilot-scale MF system and found that suspended particles, turbidity, and coliform bacteria were almost eliminated (about 4 log reductions of TC), while MS2 phage was removed by an average of 1.9 logs [50]. Even though coliphage removal was more inconsistent, Farahbakhsh and Smith in 2004 found that treating secondary effluent using an MF method resulted in 100% elimination of FC and TC (4-6 log reductions) (0.2-3.4 log) [51]. Reductions in the MS2 coliphage were found to be a 0.37-1.83 log, 1.93-3.05 log, and a 3.52-4.40 log in the UF, NF, and RO procedures, respectively. In most cases, pre-treatment is a necessary step before membrane technology can be used effectively. The scaling and fouling properties of the wastewater to be treated determine the operating life of the membrane. Currently, the cost of membrane technology is high.

- **Ultraviolet (UV) irradiation**

Ultraviolet irradiation is currently the most significant and generally adapted method of disinfection in wastewater treatment facilities [52]. The basis for ultraviolet disinfection is the ultraviolet absorption of microbial nucleic acids, which results in thymine dimerization. This hinders the reproduction of nucleic acids, which kills the cell and stops the organism from growing. The spectral range between 250 and 260 nm has the most UV light absorption, making it the best wavelength for killing bacteria [53]. The UV dosage (mWs/cm^2), which is the product of time of exposure (s) and UV intensity (mW/cm2), determines how well bacteria are destroyed.

Low-pressure mercury arc lamps are used in the most popular UV decontamination method, and they primarily generate UV light at the germicidal wavelength of 253.7 nm [37]. The output energy of a low-pressure UV lamp is fairly low (10-50W), and its output efficiency is between 30 and 40 percent. Medium-pressure UV lamps that produce polychromatic light are used in another UV disinfection method. While they produce high energy (200W), they do so with lower output efficiency. The medium-pressure ultraviolet lamps occupy smaller physical space than high-pressure ultraviolet lamps but cost more to operate due to their increased energy consumption. Disinfection reactors using ultraviolet light can either be in direct physical contact with the material being sterilized or non-contact. Contact reactors consist of UV lamps housed in quartz sleeves floating in a tank or canal of moving water. Non-contact reactors prevent water from coming into touch with UV lamps and sleeves.

Enteric microorganisms, viruses, parasite cysts, and bacterial spores can all be effectively killed by ultraviolet (UV) disinfection process. However, the sensitivity of different microorganisms to UV radiation varies greatly. Secondary and tertiary-treated wastewaters typically require UV doses between 20 and 45 mWs/cm^2 in order to realize 2-5 log decrease of indicator bacteria FC, TC, and FS. However, in order to effectively eradicate viruses, bacteria, and parasite ganglia, or to reduce bacteriological populations to extremely low levels, more potent dosages may be required [19]. Numerous variables affect UV disinfection performance, including reactor hydraulics and effluent parameters like starting bacteria populations, UV absorbance, and SS content [35]. To get the most out of an ultraviolet unit, mixing crosswise to the flow path should be increased while mixing along the flow path should be decreased. Short-circuiting is avoided and the microorganisms in the water to be treated are all exposed to roughly the same amount of UV radiation because of these parameters. The UV intensity in a reactor can be disrupted by a number of variables, including the lamp configuration and the age of the UV lamps. Water quality (such as iron, humic compounds, dissolved organic matter, and SS) has a significant effect on lamp fouling and disinfection efficiency. Impurities present in the water can reduce the efficiency of ultraviolet disinfection by either reflecting or absorbing UV rays, so shielding germs from elimination. Ultrasonic, chemical, or mechanical cleaning procedures should be used often on the UV lights [53]. This means that high-quality water fit for UV disinfection must be consistently produced by upstream treatment procedures.

Due to its many benefits, UV technology has emerged as a viable alternative to traditional disinfection strategies. The primary advantage of an ultraviolet (UV) system is the high level of disinfection it achieves without the byproducts of disinfection (such as disinfection byproducts [DBPs]) and chemical residues [54]. Ultraviolet disinfection technology eradicates the necessity for moving, storing and handling, dangerous disinfection chemicals. Unlike chemical disinfectants, ultraviolet disinfection treatment devices do not require a lot of space and only need a short contact time. UV disinfection is a risk-free and easy method of disinfection.

Two major downsides of UV disinfection are its lack of bacteriostatic action and the potential for microbial population regrowth under certain circumstances [36]. UV irradiated microbes may lose their capacity to be cultured, but continue to exist [55]. It is possible that some microorganisms that have been damaged by ultraviolet light will be able to repair themselves through a process known as enzymatic photo-reactivation or dark repair. This will enable them to continue reproducing [56]. DNA damage in microbes caused by sunlight can be restored by a process called photo reactivation (wavelength 300-500 nm). Enzymatic actions that take place in the dark allow repair to take place in the dark.

3. SECONDARY SEWAGE DISCHARGE, RECLAMATION AND REUSE

Discharge into natural waters is the most popular method for getting rid of wastewater effluent. Increases in reprocessing and reuse of wastewater have been observed in several nations in recent years. This is because wastewater reuse decreases the demand for freshwater supplies and increases the quality of surface waterways by reducing the amount of wastewater discharged into them. Irrigating farmland, flushing toilets, powering factories, cleaning up the environment, and recharging aquifers are just a few of the numerous methods by which wastewater can be put to good use again [19].

4. ULTRAVIOLET RADIATION

When it comes to disinfecting treated sewage, ultraviolet (UV) radiation is a safe and effective physical technology that doesn't rely on chemical agents and doesn't result in the formation of DBPs [57, 58]. These unintended byproducts of chlorine's combination with the natural biological effluent materials have been connected to the rise in the prevalence of cancer and other debilitating infections among humans [59]. The discharge contains modest levels of residual chlorine, which might have negative impact on aquatic life, can be reduced owing to UV's ability to remove chemical residues during the treatment process at the waste water treatment plant [60]. Therefore, UV disinfection has replaced chemical treatments as the standard for obtaining quality disinfection of effluent on both secondary and tertiary level, eliminating noxiousness and guaranteeing environmental well-being [61, 62].

Ultraviolet radiation has an anti-microbial effect between 220-320 nm, and UV includes electromagnetic radiations between X-rays and visible light at wavelengths of 100-400 nm [63]. In a traditional configuration, monochromatic (at 253.7 nm) or polychromatic (ultraviolet and visible light bands) continuous-wave mercury lamps are used [64]. Those UV lights with a 254 nm wavelength have the most effect against germs (UV-C) [65].

Particles made of solid matter can prevent the spread of ultraviolet (UV) radiation and protect bacteria from light radiation released by lamps by absorbing or scattering the light and then storing or conveying the germs they have accumulated [66]. Due to the potential for fouling issues, especially in the quartz lamp sleeves used to protect UV lamps, this treatment is therefore better suited for treated sewage with little to no suspended solids [67]. The use of other methods in conjunction with ultraviolet action is yet another possibility, as it can further reduce particle size while still retaining high disinfection efficiency [68].

Damage to nucleic acids (DNA and RNA) leads to the creation of pyrimidine dimers and other photoproducts as well as defects that disable gene transcription, hence preventing the proliferation of cells or viruses [57, 69].

DNA damage repair mechanisms are widespread among microorganisms (for example, photoreactivation and dark repair), and bacterial regeneration has also been observed [70, 71]. Repair of DNA pyrimidine dimers can occur at light intensities ranging from 330 to 480 nm (a process known as photoreactivation), or it can occur in the absence of light (dark repair). It is possible that bacterial regrowth is facilitated by photoreactivation and dark repair processes following the disinfection treatment, leading to the possibility of a re-proliferation of the germs [72]. Photoreactivation appears to be a mechanism that happens mostly at low UV levels; therefore, it may not be particularly important at full scale.

When studying the impact of UV radiation on E coli (starting concentration: 105 CFU mL^{-1}), using an ultraviolet exposure comparable to 5 $mJcm^{-2}$, found that photoreactivation was not insignificant (50%) but was unnoticeable a ultraviolet exposure values of 15 $mJcm^{-2}$, and all coliforms (initial concentrations: 96,000–250,000 CFU 100 mL^{-1}) had photoreactivation rates of less than 1% when exposed to ultraviolet radiation at 40$mJcm^{-2}$ [73, 74].

Study revealed that the average full-scale specific energy usage for UV therapy fell within the range of 0.04 to 0.13 $kWhm^{-3}$; hence this is a significant consideration [75].

Ultraviolet Light Emitting Diode

Mercury UV lamps are the most common piece of equipment used in water treatment systems, but they also have a number of serious drawbacks, including toxicity of mercury, constant wavelengths, constrained cycling and low durability. Using UV-LEDs which are compact, resilient, eco-friendly, and long-lasting ultraviolet light sources (100,000 h), could be one potential solution [76]. As a result, UV-LEDs have become more prevalent recently as a potential source for UV radiation production. To confirm that UV-LED is more effective than the other UV technologies mentioned, or at least equally effective, more research is required to look into the issue connected to the inactivation of bacteria. The use of UV-Pulsed and Continuous UV-LED to inactivate Escherichia coli in water was described by [77]; using a high power 285nm LED and low power 265 and 280 nm LED. When compared to continuous irradiation, high current pulsed illumination of 280 nm LEDs revealed an impressive inactivation improvement (approximately 3-log; about 2.5-log).

With its high and modulatable on/off frequency, UV-LED is another option to consider [78]. Song et al. investigated the efficacy of continuous and pulsed irradiation with UV-LED in killing MS2 virus and Escherichia coli bacteria in synthetic laboratory fluids and overall coliforms and E. coli in real wastewater, respectively [78, 79]. The outcomes showed that both continuous and pulsed ultraviolet LED radiation at 265nm under equal UV fluence inactivated all tested microorganisms to the same degree. Pulsed irradiation, on the other hand, can provide superior heat management for a great performance of UV-LED; therefore it seems that both continuous and pulsed irradiation is used to achieve similar inactivation. In comparison to the PUV irradiation of conventional xenon lamps, this may be an improvement. The studies summarized in Table 1 were all published within the past few years, proving that ultraviolet LED expertise is among the most cutting-edge and promising in this field.

Table 1. Several results of UV-LED disinfection tests

Type of Water	Features of Tested Water	Working Condition	Experimental Scale	Outcomes
Real Water	Domestic effluent from a sewer the system, treated with settler and sand filter	69.4 mJ cm^{-2} Exposure time: 412 s Flow rate: 10 mL min^{-1}	Flow through reactor (0.0686 L)	MS2 coliphage [b]: 3.7 ± 0.2 -log
Synthetic Water	Bacteria suspension in sterile saline solution (10^7 CFU mL^{-1})	265 nm LED: 10.91 ±0.76 mJ cm^{-2} (265 + 280) nm (50%): 12.57 ± 0.81 mJ cm^{-2} (265 + 280) nm (75%): 13.78 ± 0.67 mJ cm^{-2} 280 nm LED: 15.35 ± 1.52 mJ cm^{-2}	Lab scale reactor (0.005 L)	Escherichia coli: 4.5-log
Real Water and Synthetic Water	Deionized water, kaoline suspension (DIK), secondary effluents of urban wastewater treatment plant (SE)	30 mJ cm^{-2} Exposure time: 900 s	Batch reactor (0.03 L)	E. coli: >4.5-log (DIK), 3-log (SE)
Real Water	Secondary effluent of wastewater treatment plant with UASB treatment [b]	Wavelength (nm) / Irradiance intensity ($mWcm^{-2}$) 255 / 0.017 280 / 0.019 365 / 0.004 405 / 0.077	Lab scale reactor (0.02 L)	Wavelength (nm) / *E. coli* Inactivation log 255 / 2.6 280 / 4.0 255/280 / 3.7 255/280/405 / 3.8 280/365/405 / 3.5 255/280/365/405 / 3.8

[a.] *for the purpose of this investigation, pure cultivated Male Specific 2 (MS2) coliphage served as both a representative microbe and a biodosimeter.*
[b.] *the treated effluent used in this study was collected from an effluent treatment plant (80 Ls-1 flow rate, 90% BOD elimination efficacy) consisting of an Upflow Anaerobic Sludge Blanket (UASB), trickling filter, and circular clarifiers.*

5. CONCLUSIONS

There is no one best way to disinfect sewage; rather, each type of treated sewage requires its own specific disinfection method, with environmental effects factored in. In this article, we analyze the benefits and drawbacks of more than 80 published works on UV-based treatments. Organic matter and phosphorus could be reduced by around 95% in traditional bio-chemical wastewater disinfection process, which consist of primary and secondary treatment, with comparatively low residual amounts in secondary effluents. Although secondary effluents often contained far lower microbial loads than the primary ones, they nonetheless carried pathogenic, antibiotic-resistant salmonellae. There were instances when the quality of the wastewater declined and the secondary treatment process became less efficient, and a higher concentration of contaminants was discharged into the acquiring water body. Treatment with ultraviolet light for disinfection showed synergistic effects, indicating that using UV light could improve the efficacy and dependability of sewage disinfection.

When it comes to the major issues that prohibit the reuse of treated sewage, the microbial component is crucial. The reuse of purified effluents from sewage treatment shows tremendous promise due to the little impact on the environment from the creation of DBPs and the extremely high rate of disinfection success attained by UV-based combination processes (greater than 3-log decrease in most scenarios). However, the dearth of expertise with full-sized plant management (particularly for ultraviolet-based combination methods) and the paucity of research works on specific procedures (e.g., PEC) based on tests on synthetic waters in laboratory experiments despite real waters with relatively low scale reactor are the main factors leading to the inadequate implementation on a broader scale. Therefore, there needs to be further comprehensive research to verify the full implementation of UV-LED combined procedures in treated sewage for recycle of their disinfected wastes.

References

[1] Efstratiou A., Ongerth J.E., Karanis P., Waterborne transmission of protozoan parasites: review of worldwide outbreaks - an update 2011-2016. *Water Research* 114 (2017) 14-22

[2] Troeger C., Forouzanfar M., Rao P.C., Estimates of global, regional, and national morbidity, mortality, and aetiologies of diarrhoeal diseases: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet Infectious Disease* 17(9) (2017) 909-948

[3] Yang K., LeJeune J., Alsdorf D., Lu B., Shum C.K., Liang S., Global distribution of outbreaks of water-associated infectious diseases. *PLoS Neglected Tropical Diseases* 6(2) (2012) e1483

[4] Liberti L., Notarnicola M., Petruzzelli D., Advanced treatment for municipal wastewater reuse in agriculture. UV disinfection: parasite removal and by-product formation. *Desalination* 152(1) (2003) 315-324

[5] Azaizeh H., Linden K.G., Barstow C., Kalbouneh S., Tellawi A., Albalawneh A., Gerchman Y., Constructed wetlands combined with UV disinfection systems for removal of enteric pathogens and wastewater contaminants. *Water Science & Technology* 67(3) (2013) 651-657

[6] Bilotta P., Steinmetz R.L.R., Kunz A., Mores R., Swine effluent post-treatment by alkaline control and UV radiation combined for water reuse. *Journal of Cleaner Production* 140 (2017) 1247-1254

[7] Nance P., Patterson J., Willis A., Foronda N., Dourson M., Human health risks from mercury exposure from broken compact fluorescent lamps (CFLs). *Regulatory Toxicology and Pharmacology* 62(3) (2012) 542-552

[8] United Nations Environment Program, (2013). Minamata Convention on Mercury. Retrieved from: www.mercuryconvention.org/Convention/Text. Accessed on July 5, 2022

[9] Würtele M.A., Kolbe T., Lipsz M., Külberg A., Weyers M., Kneissl M., Jekel M.J.W.R., Application of GaN-based ultraviolet-C light emitting diodes UV-LEDs for water disinfection. *Water Research* 45(3) (2011) 1481-1489

[10] Chevremont A.C., Boudenne J.L., Coulomb B., Farnet A.M., Fate of carbamazepine and anthracene in soils watered with UV-LED treated wastewaters. *Water Research* 47(17) (2013) 6574-6584

[11] Mamane H., Ducoste J.J., Linden K.G., Effect of particles on ultraviolet light penetration in natural and engineered systems. *Applied Optics* 45(8) (2006) 1844-1856

[12] Carre E., Perot J., Jauzein V., Lopez-Ferber M., Impact of suspended particles on UV disinfection of activated-sludge effluent with the aim of reclamation. *Journal of Water Process Engineering* 22 (2018) 87-93

[13] Smith B.T. & Davis R.H., Particle concentration using inclined sedimentation via sludge accumulation and removal for algae harvesting. *Chemical Engineering Science* 91 (2013) 79-85

[14] Haig S.J., Collins G., Davies R.L., Dorea C.C., Quince C., Biological aspects of slow sand filtration: past, present and future. *Water Science and Technology: Water Supply* 11(4) (2011) 468-472

[15] Paredes L., Fernandez-Fontaina E., Lema J.M., Omil F., Carballa M., Understanding the fate of organic micropollutants in sand and granular activated carbon biofiltration systems. *Science of the Total Environment* 551 (2016) 640-648

[16] Li G.Q., Wang W.L., Huo Z.Y., Lu Y., Hu H.Y., Comparison of UV-LED and low-pressure UV for water disinfection: Photoreactivation and dark repair of Escherichia coli. *Water Research* 126 (2017) 134–143

[17] Nessim Y. & Gehr R., Fouling Mechanisms in Laboratory-Scale UV Disinfection System: a research publication of the Water Environment Federation. *Water Environment Research* 78(12) (2006) 2311-2323

[18] Arik M., Becker C., Weaver S., Petroski J., Thermal Management of LEDs: Package to System. Proceedings of SPIE - The International Society for Optical Engineering (2004) 5187.10.1117/12.512731

[19] Nasser A.M., Paulman H., Sela O., Ktaitzer T., Cikurel H., Zuckerman I., Meir A., Aharoni A., Adin A., UV disinfection of wastewater effluents for unrestricted irrigation. *Water Science and Technology* 54(3) (2006) 83-88

[20] Bitton G., Wastewater microbiology. John Wiley & Sons. (2014) pp 478

[21] Jacangelo J.G., Loughran P., Petrik B., Simpson D., Mcllroy C., Removal of enteric viruses and selected microbial indicators by UV irradiation of secondary effluent. *Water Science and Technology* 47(9) (2003) 193-198

[22] Tchobanoglous G., Schroeder E., Water quality: characteristics, modeling, modification. Reading, MA: Addison-Wesley (2015) pp 768.

[23] Stampi S., De Luca G., Zanetti F., Evaluation of the efficiency of peracetic acid in the disinfection of sewage effluents. *Journal of Applied Microbiology* 91(5) (2011) 833-838.

[24] Wagner M., Brumelis D., Gehr R., Disinfection of wastewater by hydrogen peroxide or peracetic acid: Development of procedures for measurement of residual disinfectant and application to a physiochemically treated municipal effluent. *Water Environment Research* 74(1) (2012) 33-50.

[25] Azzellino A., Antonelli M., Canziani R., Malpei F., Marinetti M., Nurizzo C., Multivariate analysis as a tool for modelling disinfection kinetics on a secondary treated wastewater: a comparison among three different disinfectants. IWA Regional Symposium on Water Recycling in Mediterranean Region, Iraklio, Greece, September 26-29, 2002. *Symposium Preprint Book 1, National Foundation for Agricultural Research. Eds.* (2012) pp 597-604.

[26] Monarca S., Feretti D., Collivignarelli C., Guzzella L., Zerbini I., Bertanza G., Pedrazzani R., The influence of different disinfectants on mutagenicity and toxicity of urban wastewater. *Water Research* 34(17) (2000) 4261-4269.

[27] Lazarova V., Savoye P., Janex M.L., Blatchley III E.R., Pommepuy M., Advanced wastewater disinfection technologies: state of the art and perspectives. *Water Science and Technology* 40(4-5) (1999) 203-213.

[28] Tyrrell S., Ripley S.P., Watkins W.D., Inactivation of bacterial and viral indicators in secondary sewage effluents, using chlorine and ozone. *Water Research* 29 (2005) 2483-2490.

[29] Veschetti E., Cutilli D., Bonadonna L., Briancesco R., Martini C., Cecchini G., Anastasi P., Ottaviani M., Pilot-plant comparative study of peracetic acid and sodium hypochlorite wastewater disinfection. *Water Research* 37(1) (2003) 78-94

[30] U.S. EPA. 1999a. Wastewater technology fact sheet. Chlorine disinfection. EPA 832-F-99- 062. Office of water, Washington D.C.

[31] Baldry M.G.C., French M.S., Slater D., The activity of peracetic acid on sewage indicator bacteria and viruses. *Water Science and Technology* 24(2) (2011) 353-357.

[32] Mujeriego R. & Asano T., The role of advanced treatment in wastewater reclamation and reuse. *Water Science and Technology* 40(4-5) (1999) 1-9

[33] Mezzanotte V., Antonelli M., Azzellino A., Citterio S., Nurizzo C., Secondary effluent disinfection by peracetic acid (PAA): microorganisms' inactivation and re-growth, preliminary results. IWA Regional Symposium on Water Recycling in Mediterranean Region, Iraklio, Greece, September 26-29, 2002. Symposium Preprint Book 1, National Foundation for Agricultural Research. Eds. (2002) pp 571-577

[34] Koukouraki E., Diamadopoulos E., Modelling the formation of THM during chlorination of treated municipal wastewater. IWA Regional Symposium on Water Recycling in Mediterranean Region, Iraklio, Greece, September 26-29, 2002. Symposium Preprint Book 1, National Foundation for Agricultural Research. Eds. (2002) pp 589-596

[35] Salgot M., Folch M., Huertas E., Tapias J., Avellaneda D., Girós G., Brissaud F., Vergés C., Molina J., Pigem J., Comparison of different advanced disinfection systems for wastewater reclamation. *Water Science and Technology: Water Supply* 2(3) (2012) 213-218

[36] Collivignarelli C., Bertanza G., Pedrazzani R., A comparison among different wastewater disinfection systems: experimental results. *Environmental Technology* 21(1) (2000) 1-16

[37] U.S. EPA. 1999d. Combined sewer overflow technology fact sheet. Chlorine disinfection. EPA 832-F-99-034. Office of water, Washington D.C.

[38] Kitis M., Disinfection of wastewater with peracetic acid: a review. *Environment International* 30(1) (2004) 47-55

[39] Caretti C. & Lubello C., Wastewater disinfection with PAA and UV combined treatment: a pilot plant study. *Water Research* 37(10) (2003) 2365-2371

[40] Liberti L. & Notarnicola M., Advanced treatment and disinfection for municipal wastewater reuse in agriculture. *Water Science and Technology* 40(4-5) (2009) 235- 245

[41] Crebelli R., Conti L., Monarca S., Feretti D., Zerbini I., Zani, C., Veschetti, E., Cutilli, D. and Ottaviani, M., Genotoxicity of the disinfection by-products resulting from peracetic acid- or hypochlorite-disinfected sewage wastewater. *Water Research* 39(6) (2005) 1105-1113

[42] Heinonen-Tanski H. & Savolainen R., Disinfection of septic tank and cesspool wastewater with peracetic acid. *AMBIO: A Journal of the Human Environment* 32(5) (2003) 358-361

[43] Sánchez-Ruiz C., Martínez-Royano S., Tejero-Monzón I., An evaluation of the efficiency and impact or raw wastewater disinfection with peracetic acid. *Water Science and Technology* 32(7) (2015) 159-166

[44] Antonelli M., Rossi S., Mezzanotte V., Nurizzo C., Secondary effluent disinfection: PMAA long term efficiency. *Environmental Science & Technology* 40(15) (2006) 4771-4775

[45] Straub T.M., Gerba C.P., Zhou X., Price R., Yahya M.T., Synergistic inactivation of Escherichia coli and MS-2 coliphage by chloramines and cupric chloride. *Water Research* 29(3) (1995) 811-818

[46] Butkus M.A., Labare M.P., Starke J.A., Moon K., Talbot M., Use of aqueous silver to enhance inactivation of coliphage MS-2 by UV disinfection. *Applied and Environmental Microbiology* 70(5) (2004) 2848-2853

[47] Sommer R., Pribil W., Pfleger S., Haider T., Werderitsch M., Gehringer P., Microbicidal efficacy of advanced oxidation process using ozone/hydrogen peroxide in water treatment. *Water Science and Technology* 50(1) (2004) 159-164

[48] Cho M., Chung H., Choi W., Yoon J., Linear correlation between inactivation of E. coli and OH radical concentration in TiO2 photocatalytic disinfection. *Water Research* 38(4) (2004) 1069-1077

[49] Sano D., Ueki Y., Watanabe T., Omura T., Membrane separation of indigenous noroviruses from sewage sludge and treated wastewater. *Water Science and Technology* 54(3) (2006) 77-82

[50] Jolis D., Hirano R.A., Pitt P.A., Müller A., Mamais D., Assessment of tertiary treatment technology for water reclamation in San Francisco, California. *Water Science and Technology* 33(10-11) (2006) 181-192

[51] Farahbakhsh K. & Smith D.W., Removal of coliphages in secondary effluent by microfiltration – mechanisms of removal and impact of operating parameters. *Water Research* 38(3) (2004) 585-592

[52] Sakamoto G., Schwartzel D., Tomowich D., UV disinfection for reuse applications in North America. *Water Science and Technology* 43(10) (2011) 173-178

[53] U.S. EPA. 1999b. Wastewater technology fact sheet. Ultraviolet disinfection. EPA 832-F-99- 064. Office of water, Washington D.C.

[54] Liberti L., Notarnicola M., Petruzzelli D., Dell´Erba A., Potential formation of byproducts during advanced disinfection of municipal wastewater with UV, ozone or peracetic acid. IWA Regional Symposium on Water Recycling in Mediterranean Region, Iraklio, Greece, September 26-29, 2002. *Symposium Preprint Book 1, National Foundation for Agricultural Research. Eds.* (2012) pp 579-587

[55] Blatchley III. E.R., Dumoutier N., Halaby T.N., Levi Y., Laîné J.M., Bacterial responses to ultraviolet irradiation. *Water Science and Technology* 43(10) (2001) 179-186

[56] Zimmer J.L. & Slawson R.M., Potential repair of Escherichia coli DNA following exposure to UV radiation from both medium- and low-pressure UV sources used in

drinking water treatment. *Applied and Environmental Microbiology* 68(7) (2002) 3293-3299

[57] Yu H., Song L., Hao Y., Lu N., Quan X., Fabrication of pilot-scale photocatalytic disinfection device by installing TiO_2 coated helical support into UV annular reactor for strengthening sterilization. *Chemical Engineering Journal* 283 (2016) 1506-1513

[58] Ghernaout D. & Elboughdiri N., UV-C/H2O2 and Sunlight/H2O2 in the Core of the Best Available Technologies for Dealing with Present Dares in Domestic Wastewater Reuse. *Open Access Library Journal* 7(3) (2020) 1-13.

[59] Hong H., Xiong Y., Ruan M., Liao F., Lin H., Liang Y., Factors affecting THMs, HAAs and HNMs formation of Jin Lan Reservoir water exposed to chlorine and monochloramine. *Science of the Total Environment* 444 (2013) 196–204

[60] Paleologou A., Marakas H., Xekoukoulotakis N.P., Moya A., Vergara Y., Kalogerakis N., Gikas P., Mantzavinos D., Disinfection of water and wastewater by TiO2 photocatalysis, sonolysis and UV-C irradiation. *Catalysis Today* 129(1-2) (2007) 136–142

[61] Taghipour F., Ultraviolet and ionizing radiation for microorganism inactivation. *Water Research* 38(18) (2004) 3940–3948

[62] Nebot, Sanz E., Salcedo, Dávila I., Andrade, Balao J.A., Quiroga, Alonso J.M., Modelling of reactivation after UV disinfection: Effect of UV-C dose on subsequent photoreactivation and dark repair. *Water Research* 41(14) (2007) 3141-3151

[63] Bonomo L. (2008) Trattamenti Delle Acque Reflue; McGraw-Hill: Ney York, NY, USA ISBN: 978-88-386-6518-9

[64] Uslu G., Demirci A., Regan J.M., Efficacy of pulsed UV-light treatment on wastewater effluent disinfection and suspended solid reduction. *Journal of Environmental Engineering* 141(6) (2015) 04014090

[65] Dos Santos A.B.K., Claro E.M.T., Montagnolli R.N., Cruz J.M., Lopes P.R.M., Bidoia E.D., Electrochemically assisted photocatalysis: Highly efficient treatment using thermal titanium oxides doped and non-doped electrodes for water disinfection. *Journal Environmental Management* 204 (2017) 255-263

[66] Cantwell R.E. & Hofmann R., Ultraviolet absorption properties of suspended particulate matter in untreated surface waters. *Water Research* 45(3) (2011) 1322-1328

[67] Wait I.W., Johnston C.T., Blatchley E.R., The influence of oxidation reduction potential and water treatment processes on quartz lamp sleeve fouling in ultraviolet disinfection reactors. *Water Research* 41(11) (2007) 2427-2436

[68] Vasilyak L.M., Ultrasound application in systems for the disinfection of water. *Surface Engineering and Applied Electrochemistry* 46(5) (2010) 489-493

[69] Hijnen W.A.M., Beerendonk E.F., Medema G.J., Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo) cysts in water: review. *Water Research* 40(1) (2006) 3-22

[70] Liltved H. & Landfald B., Effects of high intensity light on ultraviolet-irradiated and non-irradiated fish pathogenic bacteria. *Water Research* 34(2) (2000) 481-486

[71] Oguma K., Katayama H., Mitani H., Morita S., Hirata T., Ohgaki S., Determination of Pyrimidine Dimers in Escherichia coli and Cryptosporidium parvum during UV Light Inactivation, Photoreactivation, and Dark Repair. *Applied Environmental Microbiology* 67(10) (2001) 4630-4637

[72] Lee O.M., Kim H.Y., Park W., Kim T.H., Yu S., A comparative study of disinfection efficiency and regrowth control of microorganism in secondary wastewater effluent using UV, ozone, and ionizing irradiation process. *Journal Hazardous Materials* 295 (2015) 201-208

[73] Guo M., Hu H., Bolton J.R., El-Din M.G., Comparison of low- and medium-pressure ultraviolet lamps: Photoreactivation of Escherichia coli and total coliforms in secondary effluents of municipal wastewater treatment plants. *Water Research* 43(3) (2009) 815–821

[74] Hallmich C., Gehr R., Effect of pre- and post-UV disinfection conditions on photoreactivation of fecal coliforms in wastewater effluents. *Water Research* 44(9) (2010) 2885-2893

[75] Fenu A., Roels J., Wambecq T., De Gussem K., Thoeye C., De Gueldre G., Van De Steene B., Energy audit of a full scale MBR system. *Desalination* 262(1-3) (2010) 121–128

[76] Silva N.B., Leonel L.P., Tonetti A.L., UV-LED for Safe Effluent Reuse in Agriculture. *Water Air Soil Pollution* 231(7) (2020) 1-10

[77] Zou X.Y., Lin Y.L., Xu B., Cao T.C., Tang Y.L., Pan Y, Gao Z.C., Gao N.Y., Enhanced inactivation of E. coli by pulsed UV-LED irradiation during water disinfection. *Science of the Total Environment* 650 (2019) 210-215

[78] Song K., Taghipour F., Mohseni M., Microorganisms inactivation by continuous and pulsed irradiation of ultraviolet light-emitting diodes (UV-LEDs). *Chemical Engineering Journal* 343 (2018) 362-370

[79] Song K., Mohseni M., Taghipour F., Application of ultraviolet light-emitting diodes (UV-LEDs) for water disinfection: a review. *Water Research* 94 (2016) 341-349