review article

A review on wastewater disinfection

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ABSTRACT

Changes in regulations and development of new technologies have affected the selection of alternative for treated wastewater disinfection. Disinfection is the last barrier of wastewater reclamation process to protect ecosystem safety and human health. Driving forces include water scarcity and drinking water supply, irrigation, rapid industrialization, using reclaimed water, source protection, overpopulation, and environmental protection. The safe operation of water reuse depends on effluent disinfection. Understanding the differences in inactivation mechanisms is critical to identify rate-limiting steps involved in the inactivation process as well as to develop more effective disinfection strategies. Disinfection byproducts discharged from wastewater treatment plants may impair aquatic ecosystems and downstream drinking-water quality. Numerous inorganic and organic micropollutants can undergo reactions with disinfectants. Therefore, to mitigate the adverse effects and also to enhance that efficiency, the use of alternative oxidation/disinfection systems should be evaluated as possible alternative to chlorine. This review gives a summary of the traditional, innovative, and combined disinfection alternatives and also disinfection byproducts for effluent of municipal wastewater treatment plants.

Key words: Disinfection byproducts, human and environmental health, wastewater disinfection

INTRODUCTION

Disinfection is the last barrier of wastewater reclamation process to protect ecosystem safety and human health.[1] The use of ecologically friendly wastewater disinfection techniques could be one of the most exciting advances in this field.[2] Many countries face water challenges due to water scarcity caused by climatological and demographic pressure.[3] The environmental and social impact derived from treated wastewater reuse is an intrinsically complex multidimensional process, which involves multiple criteria and multiple stakeholders. Economic criteria showed priority in the most entrepreneurial uses of the water, although social and political cost had a greater weight in the case of environmental or recreational uses. The inclusion of environmental and social assessment in the disinfection technique decision support clearly provides a cleaner and more sustainable production.[4] Advances in wastewater treatment technology have led many to predict that planned wastewater reuse in agriculture will soon become more common in some regions of the world, which face acute problems of water quality and quantity.[2] The main function of a wastewater treatment plant is to minimize the environmental impact of discharging untreated wastewater into natural water systems.[5] Municipal sewage effluents are complex mixtures

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that are known to compromise the health condition of aquatic organisms.[6] Rapid industrialization, growing human population, and related issues have seriously affected human health and environmental sustainability. For conservation and sustainable use of our water resources, innovative methods for wastewater treatment are continuously being explored.[7]

The objective of this review was to elucidate application of common wastewater disinfectants such as chlorine compounds, ozone, ultraviolet (UV), macro filtration and biological processes, and innovative unit operation and processes including membrane filtration, ultrasound, gamma ray, hybrid techniques, nanomaterials, electrochemical, and further technologies.

Chlorination/Dechlorination

Chlorine is conventional disinfectant. However, effluent chlorination results in the formation of mutagenic/carcinogenic disinfection by-products (DBPs) deriving from the reaction of the chlorine with organic compounds in wastewater.[1] Therefore, dechlorination followed by chlorination should be done, or alternative safe disinfectant should be used.

Chlorination byproducts

DBPs discharged from wastewater treatment plants may impair aquatic ecosystems and downstream drinking-water quality.[8] The chlorination process results in the formation of mutagenic/carcinogenic DBPs deriving from the reaction of the chlorine with organic compounds in wastewater.[1] Some of these substances have proven to be carcinogenic in humans and animals. Because it is not possible to detect all DBPs produced in chlorinated wastewater, toxicity tests have been proposed as a useful tool for screening toxic chemicals in treated wastewater. The Microtox® bioassay with Vibrio fischeri has been used to evaluate the formation of toxic by-products in wastewater, after a chlorination-dechlorination disinfection treatment. Toxicity increases with the Cl_2:NH_4^+ ratio at a higher chlorine concentration released from combined chlorine.[9]

The effects of operating conditions (chlorine dose, contact time, reaction temperature, and pH value) of chlorination on the formation of trihalomethanes (THMs) and haloacetic acids (HAAs) in biologically treated wastewater samples has been indicated that the total THMs (TTHMs) and total HAAs (THAAs) increase exponentially with increasing chlorine dose, but there are discrepancies between the formation rates of TTHMs and THAAs.[1] Formation of regulated and non-regulated disinfection by-products (DBPs) in potable water and wastewater treatment plants (W/WWTPs) has been determined in the presence of free chlorine and chloramines and have been obtained for THMs, HAAs, haloacetonitrile (HAN), and N-nitrosodimethylamine (NDMA). These are the first such DBP formation potentials models for wastewater systems and among the few models that consider both carbonated DBPs (C-DBPs) and nitrogenated DBPs (N-DBPs). formation.[10] Ozonation prior to chlorination practice exhibits a negative effect on THMs and haloketones reduction.[11]

Formation potential tests performed on WWTP effluents revealed that halonitromethanes (HNMs) formation as one class of emerging disinfection by-products with high potential health risks has been occurred in the order of ozonation-chlorination >> ozonation-chloramination > chlorination > chloramination. Ozonation alone did not produce any HNM. The nitrification in WWTPs appears to remove appreciable portion of HNM precursors, especially those reactive to chlorine. Therefore, it seems the typical wastewater disinfection processes involving chlorination or UV treatment in WWTPs do not produce significant amounts of HNMs.[12]

The formation of total THMs and total HAAs during chlorine disinfection increases with increasing bromide levels in wastewater. The formation of $CHBr_3$ increases nearly linearly with increasing bromide ion levels, while $CHCl_2Br$ and $CHClBr_2$ increase with increasing bromide concentration from 0 to 3.2 mg/L and thereafter remain constant or slightly decrease. The distribution of monohalogenated, dihalogenated, and trihalogenated species of HAAs in chlorinated wastewater at high concentration of bromide (>2 mg/L) is different from that of drinking/natural water.[13]

Recent studies have reported that genotoxicity is increased significantly in wastewater with a high ammonia concentration after chlorination. The bromine incorporation factors n (Br) and n'(Br), as a function of ammonia concentration, are influenced by the Br-/N mass ratio in wastewater chlorination and are constant when the Br-/N mass ratio is lower than 0.003 (or 0.53 [mu] M/mM) due to the low concentrations of bromide ions.[14]

Results of the study on the trihalomethane formation potential (THMFP) indicates that hydrophobic acid (HPO-A) and hydrophilic fraction (HPI) dominated in the secondary effluent, collectively accounting for more than 66% of the dissolved organic matter (DOM) as dissolved organic carbon and 70-84% of the THMFP of DOM, was converted from the reaction of chlorine with HPO-A and HPI.[15]

Organic matter is known to be the precursor of numerous chlorination by-products in the secondary effluent from the wastewater treatment plant. The ratio of aliphatic to aromatic protons increases in the order of HPO-A < hydrophobic neutral (HPO-N) < transphilic acid (TPI-A) < transphilic neutral (TPI-N). Fourier transform infrared spectroscopy (FT-IR) analysis of the four fractions show that HPO-A had greater aromatic content, whereas HPO-N, TPI-A, and TPI-N had greater aliphatic C-H content.

TPI-N contains more oxygen-containing functional groups than the other fractions.[16]

Sodium hypochlorite (NaOCl)

A two-stage disinfection system consisting of a chemical step (mild chlorination) followed by a natural one (filtration through a horizontal subsurface flow (HSF) bed) has been carried out on a pilot plant for a secondary biological effluent. Disinfection, with low doses of NaClO (2 mg/L of disinfectant and a retention time of 30 min, corresponding to an applied dose of 2 × 30 = 60 mg/L. min) and a well designed final subsurface flow system, is able to obtain an effluent complying with reuse quality limits, in particular for microbiological parameters.[17]

Electrochemical disinfection/Online chlorination

Electrochemical disinfection has gained increasing attention due to its high effectiveness and environmental compatibility.[18] Although increased attention has been paid for on-line chlorine dioxide generation by several chemical and electrochemical methods, the details are mostly confined as patents. The electrochemical generation of chlorine dioxide from an un-buffered solution of sodium chlorite and sodium chloride mixture in an un-divided electrochemical cell under constant current mode, with a view to optimize various process parameters, has been studied, which have a direct bearing on the chlorine dioxide formation efficiency under laboratory conditions.[19]

The effect of OH radicals in case of the direct electrochemical disinfection of chloride-containing secondary effluents of biologically-treated sewage with boron-doped diamond electrodes (BDD) is negligible because of their fast reaction with typical radical scavengers. The dominating role of electrochemically generated free chlorine in the disinfection process could be explicitly verified. It could be also shown that the disinfection efficiency is strongly affected by the specific wastewater parameters such as temperature and pH.[20]

A study on the electrochemical disinfection with H_2O_2 generated at the gas diffusion electrode (GDE) from active carbon/polytetrafluoroethylene was performed in a non-membrane cell. The experimental results showed that nearly all bacterial cultures inoculated in the secondary effluent from wastewater treatment plant could be inactivated within 30 min at a current density of $10 mA/cm^2$. The germicidal efficacy in the cathode compartment was approximately the same as in the anode compartment, indicating that the contribution of direct oxidation and the indirect treatment of bacterial cultures by hydroxyl radical was similar to the oxidative indirect effect of the generated H_2O_2.[21]

The most common method of electrochemical disinfection is the use of electro-generated oxidants, such as active chlorine and reactive oxygen species, as disinfectants. The role of electrode material on the generation of oxidants and elucidated the different reaction pathways for generating individual oxidants has been examined. The OH was found to play a key role in O_3 generation at boron-doped diamond (BDD), but not at the other electrodes. The production of active chlorine was in the order of $Ti/IrO_2 > Ti/RuO_2 > Ti/Pt\text{-}IrO_2 > BDD > Pt$.[18]

Chlorine dioxide (ClO_2)

Chlorine dioxide is potentially a powerful oxidant with environmentally compatible application in several strategic areas relating to pollution control typically for water disinfection, and its sustained production is a key factor for its successful application.[19] Chlorine dioxide is a hypochlorite alternative disinfectant agent.[22]

In a study, the bactericidal effect of chlorine dioxide in untreated artificial and domestic wastewaters and secondary effluent of various organic loads has been examined. Results indicate that the inactivation of *Escherichia coli* in artificial wastewater is similar with that in real municipal wastewater. Among three waters, the bactericidal effect of chlorine dioxide was lowest in secondary effluent. The bacteria log inactivation increase by up to threefold when the COD concentration of raw wastewater is decreased by half.[23]

Chloramines

The presence of nitrosamines in wastewater might pose a risk to water resources, even in countries where chlorination or chloramination are hardly used for water disinfection. N-nitrosodimethylamine NDMA among eight N-nitrosamines is the predominant compound in primary effluents of 21 full-scale sewage treatment plants in the Switzerland with median concentrations in the range of 5-20 ng/L, but peak concentrations up to 1 [mu] g/L. N-nitrosomorpholine (NMOR) is abundant in all the plants at concentrations of 5-30 ng/L, other nitrosamines has been occurred at a lower number of the plants at similar levels.[24]

Effect of micropollutants on chlorination

Numerous inorganic and organic micropollutants can undergo reactions with chlorine. For the most micropollutants, HOCl is the major reactive chlorine species during chlorination processes.[25] The products formed in the reaction of ClO_2 with selected amino acids as model compounds have been determined. The reaction of tryptophane, histidine, and tyrosine (10 ppm each) with ClO_2 has been studied at molar ratios ranging from 0.25 to 4 in the presence or absence of oxygen. The reaction product distribution revealed that chlorine dioxide can attack the electron-rich aromatic moieties as well as the nitrogen atom lone electron pair.[22]

The reaction of the drug atenolol with hypochlorite under conditions that simulate wastewater disinfection has been investigated. The pharmaceutical is reacted in 1 h yielding three products that are separated by chromatographic techniques and characterized by spectroscopic features.

Two unusual products 2-(4-(3-(chloro (2-chloropropan-2-yl) amino)-2-hydroxypropoxy) phenyl) acetamide and 2-(4-(3-formamido-2-hydroxypropoxy) phenyl) acetamide are obtained along with 2-(4-hydroxyphenyl) acetamide. When the reaction is stopped at shorter times, only 2-(4-(3-amino-2-hydroxypropoxy) phenyl) acetamide and the dichlorinated product are detected. Tests performed on the seeds of Lactuca sativa show that chlorinated products have phytotoxic activity.[26]

The potential reactions of tetracyclines (TCs) with common water disinfection oxidants such as chlorine dioxide (ClO_2) and free available chlorine (FAC) have not been studied in depth and are the focus of a study. The results indicate that rapid transformation of by oxidants such as ClO_2 and FAC under water and wastewater treatment conditions can be expected.[27]

OZONATION

Disinfection with ozone

Disinfection of anaerobic sanitary wastewater effluent with ozone has been done at doses of 5.0, 8.0, and 10.0 mg O_3/L for contact times of 5, 10, and 15 min. The total coliform inactivation range is 2.00-4.06 log10, and the inactivation range for *Escherichia coli* is 2.41-4.65 log10.[28]

The disinfection capacity of the ozone full-scale reactor treating secondary wastewater effluent has been assessed to be 1-4.5 log units in terms of total cell counts (TCC) and 0.5 to 2.5 log units for *Escherichia coli* (*E. coli*). Regrowth of up to 2.5 log units during sand filtration is observed for TCC while no regrowth occurred for *E. coli*. *E. coli* inactivation could not be accurately predicted by the model approach, most likely due to shielding of *E. coli* parameter by flocs.[29]

Dissolved ozone flotation (DOF) and conventional mechanical diffuser ozonation systems have been applied to treat the downstream municipal wastewater. In the optimum, ozone dose of 6.1mg/L is found in the DOF. Almost 100% disinfection efficiency was achieved by removing heterotrophic and coliform bacteria. DOF technology is very effective and economically viable for municipal wastewater treatment in the present day context.[30]

Ozonation byproducts

Results of the experiment on coliform inactivation and disinfection byproducts (DBPs) formation reveals the fact that aldehydes and carboxylic acid formation are significantly related with the ozone dose and exposure time. Ozone might enhance the treatment efficiency of secondary effluent treatment.[31]

Aldehyde formation in disinfection of anaerobic sanitary wastewater effluent varies with dosage only when the ozone dose is increased from 5 to 8 mg O_3/L for acetaldehyde and from 5 to 8 and from 8 to 10 mg O_3/L for glyoxal.[28]

An increase in the formation of bromate, a potential human carcinogen, during ozonation of the secondary wastewater effluent has been observed with increasing ozone doses. NDMA formation of up to 15 ng/L has been detected in the first compartment of the ozone reactor, followed by a slight elimination during sand filtration. Assimilable organic carbon (AOC) increases up to 740 [mu] g AOC/L, with no clear trend when correlated to the ozone dose, and decreases by up to 50% during post-sand filtration.[29]

Ozonation enhance the yields of all detected chlorine DBPs, except CHCl3 during post-chlorination of tertiary effluent from a sewage treatment plant. At a chlorine dose of 5 mg/L, the three brominated THMs and five HAAs increased, while chloroform decreased with the increase of ozone dose from 0 to 10 mg/L (ozone dose in consumption base). Chlorination could further remove the genotoxicity to some extent.[32]

Up to 81.7%, 76.1%, and 81.3% of DOC, THMs precursors, and HAA precursors are removed after the catalytic ozonation followed by biofiltration in a fluidized bed reactor (FBR), respectively. The proportion of bromine-containing species from the THMs and HAAs increase in water samples after being treated by biofiltration alone, ozonation alone, catalytic ozonation, and catalytic ozonation followed by biofiltration.[33]

The immunotoxic potential of a primary-treated municipal effluent following enhanced disinfection by ozonation has been studied in the freshwater mussel *Elliptio complanata*. In conclusion, ozonation of a primary-treated effluent successfully reduce microbial loading and completely remove cytotoxicity, but increase the inflammatory properties of the effluent.[34]

Catalytic ozonation of dimethyl phthalate (DMP) in aqueous solution (5 mg/L) has been performed. Ru/AC + O_3 process was much more effective than ozonation alone for TOC removal and the reduction of disinfection by-product formation potential.[35]

RADIATION

Non-ionizing radiation

Ultraviolet radiation

Disinfection of municipal wastewater effluent has been evaluated using three alternatives, including: (1) low-pressure (LP) + medium-pressure (MP) UV lamps; (2) clarifier + LP + MP; and (3) pressurized sand filter + LP + MP. Filtration + MP lamp met the standards of 1000 and 400 total and fecal coliform counts per 100 mL for effluent discharge to receiving waters. This process can also inactivate fecal *Streptococcus*, effecting a 6-log reduction.[36]

As nucleic acids are major targets in bacteria during standardized UV disinfection (254 nm), inactivation rates also depend on bacterial DNA repair. Despite high UV-mediated inactivation rates, original wastewater bacteria seem to express an enhanced robustness against irradiation. Regeneration of dominant and proliferation of low-abundant, probably UV-resistant species contributed to a strong post-irradiation recovery accompanied by a selection for [beta]-Proteobacteria.[37]

The application of Chick-Watson model in its original form is not representative of the kinetics of UV disinfection of secondary-treated wastewater. On the other hand, the application of Collins-Selleck model demonstrates that it is necessary to exceed a least dose of critical radiation to start the process of inactivation. However, the application of a new kinetic model by introducing a third factor reflecting the influence of suspended solids in water on disinfection kinetics appeared to be determinant for modeling UV inactivation of *P. aeruginosa* in secondary-treated wastewater.[38]

Nonylphenol has been found in UV-treated wastewaters. Results of the determination of nonylphenol in oysters collected from a lake in Southwest Louisiana show that none has been detected. Preliminary results on laboratory-generated reaction of nonylphenol in water with chlorine and hydrochloric acid show a decrease in nonylphenol.[39]

Previous researches have shown that wastewater disinfection using UV light can be impaired by attenuation of the UV light as it passes through particles to reach embedded and protected microorganisms. This study show that the UV absorption (at 254 nm) of particles presents in 10 untreated surface waters is similar to the absorption of wastewater particles. The study also demonstrates that there is no correlation between the UV absorption (254 nm) of the solid particulate material, TOC, total suspended solids, turbidity, or UV absorbance (254) of the bulk water.[40]

For disinfection purposes where the use of mercury-based UV sources is restricted or undesirable, a similar design approach could be used to develop an excimer UV reactor for disinfection of other fluid media, including wastewater or air.[41] In contrast to chemical disinfectants, cell inactivation by UV occurred without any liquid quality changes measurable with the methods employed.[42]

Ultrasonic radiation

US irradiation is well known as a useful technique for microbial inactivation due to its chemical and physical factors. Recent studies indicate that the presence of titanium dioxide (TiO_2), known as a photocatalyst, accelerates the generation of hydroxyl (OH) radicals during US irradiation, a so-called “sonocatalytic disinfection” method, and that the process is mediated through the induction of cavitation bubbles in irradiating solutions.[43]

The influence of three parameters: Particle origin (raw wastewater or from the aeration basin of the activated sludge process), particle concentration, and particle size on the percentage of particle breakage after ultrasound treatment has been compared. The findings reveal that raw wastewater and aeration basin particles of the same size fraction (90-106 [mu] m) responded to ultrasound in a similar way.[44]

Ionizing radiation

Gamma ray

The effects of gamma irradiation on wastewater by measuring differences in the legislated parameters, aiming to reuse the urban wastewater, have been investigated. Effluents samples have been irradiated at different doses ranging from 0 to 14 kGy using a Co^{60} gamma source. The results show an elimination of bacterial flora, a decrease of biochemical and chemical oxygen demand, and higher conservation of nutritious elements.[45]

Membrane

Membrane separations are powerful tools for various applications, including wastewater treatment and the removal of contaminants from drinking water and reusing treated wastewaters.[46]

Using municipal secondary effluent as feed, the average resistance of the microfiltration (MF) membrane to permeate flux at the end of a filtration cycle was at least 10 times of that using clean water as feed and the resistance was comparable for filtration with and without the sand filter. The decay in specific permeate flux (SPF) as a result of the resistance during the filtration followed a first order kinetics with a half-live time of 198 h with and 74 h without the sand filter in front of the MF.[47]

The effectiveness of microfiltration and ultrafiltration as pretreatments for a reverse osmosis system producing high quality reclaimed water from the effluent of a municipal wastewater treatment plant receiving a high percentage of industrial wastewater has been compared. Percentages of salt rejection is above 99%, efficiencies in the removal of microorganisms is lower values than 1 CFU/100 mL, and final COD results is below the detection limit (<5mg/L). Achieving constant disinfection and a good performance are very important factors to be considered in order to fight against fouling.[48]

The comparison of the operation of two similar tertiary membrane filtration units treating the effluent of two different sequencing batch reactor (SBRs) including a granular sludge SBR and a membrane flocculent sludge SBR system indicate that the presence of either granules or flocs in the tertiary membrane filtration systems did not have an appreciable impact on the membrane filtration. Although, the operation of the membrane on the flocculent system tends to be more instable, showing a major tendency to achieve critical flux.[49]

A study on greywater treatment has been included chlorination with hypochlorite and sand filtration. The osmosis rejection flow improves considerably the quality parameters of the treated greywater. The average reused flow is 50 m^3/day, which corresponds to 26.7 m^3 greywater/day and 23.3 m^3 osmosis waste rejection/day. The cost of reusing was estimated as [euro] 1.14 for each m^3 of reused wastewater.[50]

Miscellaneous disinfection methods

Biological methods

Wetlands varied in size, age, vegetation, hydrologic residence time (0.9-20 days) and water management (continuous flow vs. flood pulse). Important information for optimizing the design and management of constructed wetlands to effectively combine control of disinfection byproduct precursors with other water quality parameters was provided.[51]

Land infiltration

Recharge of wastewater in an unconsolidated poorly sorted alluvial aquifer is a complex process, both physically and hydrochemically. Shallow groundwater, at depths of 50 m below the surface, is contaminated with *E. coli* concentrations as high as 106 CFU/100 mL. In general, *E. coli* concentrations decrease only 3 log units from the point of infiltration to shallow groundwater. In laboratory columns of disturbed sediments, bacteria removal is 2-5 log units/0.5 cm column sediment.[52]

Filtration

Three macrofiltration processes has been evaluated as a first stage of tertiary treatment of municipal wastewater. The processes studied are pressure sand filter (PSF), disc filter (DF), and mesh filter (MF). All effluent contained *E. coli* and pathogenic nematode eggs are not detected. These technologies may be applied as pre-treatment of tertiary disinfection process, pointing up the PSF as the most effective process, allowing direct water reuse for uses with lower quality demands.[53]

Nanotechnology

Nanotechnology has widespread application in agricultural, environmental, and industrial sectors. Nanomaterials that have been used include titania, alumina, silica, silver and many others.[46] However, there have been serious implications, which are coming into light in the recent years within different environmental compartments, namely air, water, and soil and its likely impact on the human health. The escape of nanoparticles into the effluent will contaminate the aquatic and soil environment.[54]

Products with antimicrobial effect based on silver nanoparticles are increasingly used. The majority of silver released into wastewater is incorporated into sewage sludge and may be spread on agricultural fields. The amount of silver reaching natural waters depends on the fraction of wastewater that is effectively treated.[55]

Disinfection behavior of silver-modified clinoptilolite-heulandite rich tuff (ZSAg) as an antibacterial agent against coliform microorganisms has been investigated. The silver recovery does not depend on the mass of the sodium zeolitic bed according with the wastewater to be treated (synthetic or municipal wastewater), and the presence of NH_4^+ or Cl^- ions in the influent also influenced the silver recovery from wastewater.[56]

The killing effect of nano palladium-loaded on nano tungsten trioxide (n-Pd/n-WO^3) on coliform bacteria has been characterized by means of selective culture media. This process is cost-effective because no bacteria re-growth was recorded under optimum environment conditions.[57]

Wastewater-like and municipal wastewater disinfection using Mexiacan silver zeolites from Oaxaca and Sonora (Ag-OZ or Ag-SZ) and exchanged with silver ions has been investigated. The amount of silver in both the wastewater-like and municipal wastewater has been analyzed after treatment with the silver zeolites. The kinetic constants show that the decay rate of the total coliforms using Ag-OZ is higher than Ag-SZ.[58]

Electroporation

During the last years, the pulsed electric field (PEF) method entered several fields of application. A promising application is the decontamination of hospital wastewater effluents, which are loaded with pathogenic and increasingly with antibiotic-resistant bacteria. In serial experiments with 10 pulses (100 kV/cm and 600 ns pulse duration), the inactivation rate has been calculated with 3.5 ± 0.8 log of *Pseudomonas putida* colony forming units and remained constant over 30 cycles.[59]

Photovoltaic method

The combined action of a photosensitizer (meso-substituted cationic porphyrin, TMPyP; rose Bengal, RB; methylene blue, MB) and visible light, particularly sunlight, seem to be a promising approach to microbial inactivation, potentially applicable for disinfection of domestic effluents. Photosensitization has been either performed on Gram-positive and Gram-negative bacteria in pure culture (*Enterococcus hirae* and *Escherichia coli*), or is carried out with wild strains in secondary wastewater effluent (*Enterococci* and *E. coli*).[2]

Combined disinfection methods

In many countries, very stringent limit for chlorination by-products such as trihalomethane has been set for wastewater reuse. Accordingly, the use of alternative oxidation/disinfection systems should be evaluated as possible alternative to chlorine.[60] For the same level of cell inactivation by chemical disinfectants, cell surface damage was more pronounced with strong oxidant such as ozone while damage in inner cell components was more apparent with weaker oxidant such as free chlorine. Chlorine dioxide showed the inactivation mechanism between these two disinfectants.[42]

UV, Ozone, and PAA

The impacts of various wastewater disinfection processes including ultraviolet (UV) radiation, ozonation, and per acetic acid (PAA) on the immune system of juvenile rainbow trout (*Oncorhynchus mykiss*) has been evaluated. The disinfection strategy used can modify the immune system in fish at the level of T lymphocyte proliferation but was effective to remove the effects on phagocytosis activity.[6]

Filtration, UV, and UF

Settling (with and without chemicals addition), conventional sand filtration, UV disinfection, and ultrafiltration can be applied with the aim of the wastewater reclamation. The most efficient conventional alternative consisting in settling + filtration + UV radiation and the treatment including ultrafiltration eliminated almost the 100% of the total coliforms.[61]

UV, Cl_2, and H_2O_2

No synergism is observed when the UV irradiation treatment is followed by free chlorine, i.e., the overall level of inactivation is the same as the sum of the inactivation levels achieved by each disinfection step. With the addition of H_2O_2 in the primary UV disinfection step, however, enhanced microbial inactivation is observed.[62]

UV and H_2O_2

Complete disinfection of coliform bacteria has been occurred by using 40% H_2O_2/UV. The most interesting part of the research is to compare the effectiveness of waste H_2O_2 with fresh H_2O_2. Waste H_2O_2 generated from an industrial process of disinfection has been more effective in the treatment of municipal wastewater treatment than fresh 35% H_2O_2.[7]

US and ClO_2

A sequential combination of US (150 or 300 W/L) and $ClO_{2\,(}$2 mg/L) provide about 3.2-3.5log reduction in the number *E. coli* and TC in raw wastewater, while the sum of log reductions by the individual treatments are 1.4-1.9. However, the measured inactivation rate with the combination of ultrasound and ClO_2 in synthetic wastewater or secondary effluent is the same as the sum of the log inactivation with individual treatments. The enhancement attained by combined US and ClO_2 disinfection methods has been attributed to the presence of high concentration of particles in raw wastewater and their break up under shock sound waves.[63]

US and UV

An important enhancement of UV disinfection ability has been observed in presence of US, especially with wastewater characterized by low transmittance. In particular, the inactivation is greater for T. coliform than for *E. coli*. Furthermore, the results obtained show also that the fouling formation on the lamps is slower in US-UV reactor than in UV reactor, both with and without solar radiation.[60]

ClO_2 and fumaric acid

The combined treatment of 50 ppm ClO_2 and 0.5% fumaric acid reduce the initial populations of *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Listeria monocytogenes* inoculated on broccoli sprouts by 2.39, 2.74, and 2.65 log CFU/g, respectively, compared to the control. The combination of aqueous ClO_2 and fumaric acid can be useful as a hurdle for extending the shelf life of broccoli sprouts during storage.[64]

Hydrogen peroxide and ozone (peroxone)

The ozonation and ozonation plus hydrogen peroxide disinfection treatment technologies have similar environmental profiles. However, most of the indicators are about 50% higher than the ultraviolet disinfection, except for the acidification (100% higher) and photochemical oxidation (less than 5%).[5]

Hybrid of membranes and nanomaterials

The role of engineered nanomaterials in (pressure-driven) membrane technology for water treatment, to be applied in drinking water production and wastewater recycling, has been studied. Benefits and drawbacks are described, which should be taken into account in further studies on potential risks related to release of nanoparticles into the environment.[46]

CONCLUSION

Overview of studies in the years 2008 to 2010 shows that extensive researches have been done around the world in the field of urban wastewater disinfection. The range of the researches is included all areas of disinfection such as technical and operational aspects, health, environmental, chemical, toxicological, genetic and microbiological aspects.

Disinfection byproducts (DBPs) has been qualified using the highly accurate detection devices and has been quantified in the very low detection limits in the range of nano-grams per liter or less. Innovative genotoxicity and bioassay tests have been done to evaluate the effects of DBPs on microscopic and macroscopic organisms. The carcinogenic and teratogenic effects of this compound have also been studied. Numerous inorganic and organic micropollutants can undergo reactions with disinfectants.

In addition, doing research to optimize conventional disinfection methods of urban-treated wastewater, including chlorination, ozonation, ultraviolet radiation, and filtration, extensive studies introduce new methods of disinfection including the use of nanomaterials, membrane methods, ultrasonic gamma rays, photovoltaic method, electroporation, and other technologies. Electrochemical or online disinfection has also gained increasing attention due to its high effectiveness and environmental compatibility.

Combined disinfection methods including various alternatives through hybridization of UV, ozone, peracetic acid, Cl_2, ClO_2, H_2O_2, ultrasonic, fumaric acid, and also hybrid of membranes and nanomaterials has been investigated.

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