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Photolytic treatment of organic constituents and bacterial pathogens in secondary effluent of synthetic slaughterhouse wastewater

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ABSTRACT

The reduction and degradation of total organic carbon (TOC) and bacteria from a secondary effluent of synthetic slaughterhouse wastewater using vacuum-ultraviolet (VUV) and ultraviolet-C (UV-C) processes and their combination (UV-C/VUV and VUV/UV-C) were investigated. The TOC removal rates under continuous mode operation ranged from 5.5 to 6.2%. In addition, the treatment with the UV-C/H_2O_2 and VUV/H_2O_2 processes under continuous mode operation doubled the TOC removal rates 10.8 and 12.2%, respectively. The optimum molar ratio of H_2O_2/TOC was found to be 2.5 and 1.5 for the UV-C and VUV processes, respectively. It was observed that all photochemical processes were able to totally inactivate different strains of bacteria with concentrations up to 10^5 CFU/mL within 27.6 s. Finally, a kinetic model was developed to simulate the TOC degradation from a secondary effluent of synthetic slaughterhouse wastewater.

Keywords: Slaughterhouse wastewater; Secondary effluent; Advanced oxidation processes; AOP; Vacuum-UV; Total organic carbon; Combined processes

1. Introduction

Human activities such as industrial and agricultural production as well as urbanization are the principal sources of water pollution. Globally, significant amounts of hazardous organic materials and pathogenic microorganisms are discharged into receiving waters daily. With the increased societal awareness of the importance of water, a mandate for clean water sources is being supported by new and more stringent regulations (Oller et al., 2011). Such regulatory pressure is driving the development of new purification technologies in the field of water and wastewater treatment.

Slaughterhouse facilities use vast volumes of fresh water daily for numerous cleaning procedures, including carcass blood washing, equipment sterilization, and work area cleaning (Wang et al., 2006). In fact, more than 65% of the water used in slaughterhouses can be attributed to cleaning, spraying, and rinsing activities. The remaining 35% is associated with the personal hygiene, cooling water scald tank, tool sterilization, and animal handling facilities and vehicles washing (Wang et al., 2005). As a result, high loads of organic content are present in slaughterhouse wastewater effluents. In addition to the high level of organic compounds, pathogenic microorganisms such as *Escherichia coli* O157:H7, *Shigella* spp.,

Abbreviations: AOPs, advanced oxidation processes; COD, chemical oxygen demand; CFU, colony forming unit; CFD, computational fluid dynamics; DBPs, disinfection by-products; GPM, gallons per minute; HAAs, haloacetic acids; HRT, hydraulic retention time; LPM, liters per minute; LVREA, local volumetric rate of energy absorption; TOC, total organic carbon; THMs, trihalomethanes; U.S. EPA, U.S. Environmental Protection Agency; WHO, World Health Organization.

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Nomenclature

A	local volumetric rate of energy absorption (LVREA) (Einstein/(L s))
C_i	concentration of component i (M)
D	diffusivity (m^2/s)
f_i	fraction of photons absorbed by species i
h	Planck's constant $6.62606876 \times 10^{-34}$ (J s)
k	second order reaction rate constant (1/(M s))
$k_{s(\lambda)}$	specific rate of light absorption by TOC (Einstein/(mol s))
Q	volumetric flow rate (L/min)
q	radiant energy flux (Einstein/(m^2 s))
q_o	radiant energy flux on the sleeve wall (Einstein/(m^2 s))
r	position on r-axis for single lamp photoreactor (m)
R_t	photoreactor radius (m)
Re	Reynolds number
R_i	quartz sleeve radius (m)
$R_{rxn,i}$	rate of reaction of component i (M/s)
z	position on the z-axis (m)

Greek letters

ε_i	molar absorptivity of component i (1/(M m))
α	decadic absorption coefficient (1/m)
ϕ	quantum yield (mol/Einstein)
λ	wavelength (nm)
ρ	density (kg/m^3)
μ	dynamic viscosity (kg/(m s))
μ_s	solution extinction coefficient at 254 nm (1/m)
μ_w	water extinction coefficient at 254 nm (1/m)

and *Salmonella* spp. and veterinary antibiotics used to control pathogens and ensure livestock weight advancement and disease prevention, are released during the evisceration process (U.S. EPA, 2002; Kumar et al., 2005).

The introduction of organic constituents into natural source waters may cause a variety of environmental impacts, such as eutrophication, temperature change, and dissolved oxygen depletion, which can have a severe impact on the ecosystem (UNEP, 2000). Slaughterhouse wastewater effluents contain chemical oxygen demand (COD) concentrations between 3000 and 30,000 mg/L with blood as one of the major contributors (U.S. EPA, 2002; Metcalf and Eddy, 2003; Wang et al., 2006). Organic compounds consume the oxygen intended for fish and other benthic organisms, leading to such problems as reproduction, developmental abnormalities, and even death, which could trigger biodiversity losses. Likewise, hot water and steam used for sterilizing and cleaning are responsible for thermal pollution, which may become a major issue for organisms that have a narrow tolerance to temperature changes in water (UNEP, 2000; World Bank, 2005).

Conventional wastewater treatment processes such as chemical coagulation, sedimentation, filtration, adsorption, biological processes, chlorination, ozonation, and potassium permanganate oxidation are good for achieving organic matter removal (Reynolds and Richards, 1996; Metcalf and Eddy, 2003). However, these conventional technologies fall short in removing recalcitrant contaminants which leads to effluents that and often do not satisfy the discharge regulatory levels or subsequent reclaimed water reuse standards. In particular, biological processes, which are widely used for wastewater treatment, are highly sensitive to toxic compounds such as toluene, dichloromethane, benzene, and methanol derived from industrial processes, including the manufacturing of pharmaceuticals, dyes, or plastics, which are noxious to the bacteria inhibiting their ability to properly metabolize the target pollutants (Metcalf and Eddy, 2003; Hickey and Ganderton, 2010). Anaerobic treatment, which is usually employed in treating high strength wastewater effluents, removes between 85 and 90% of organic matter resulting in secondary effluents with biochemical oxygen demand (BOD) values between 100 and 150 mg/L (Wang et al., 2006). These effluents do not comply with discharge regulations, which require BOD values to be less than 30 mg/L (Environmental Commissioner of Ontario, 2010). More importantly, conventional processes do not remove trace concentrations of emerging contaminants such as pharmaceutical active compounds (PhACs), bisphenol A, personal care products, trichloroethene, neurotoxins, endocrine disruptors, and perfluororinated surfactants (Aga, 2008; Auriol et al., 2006; Barcelo and Petrovic, 2008; Pereira et al., 2011). Disinfection technologies, such as chlorination and ozonation used to inactivate disease-causing microorganisms, are responsible for the generation of hazardous compounds known as disinfection by-products (DBPs). DBPs include, but are not limited to, trihalomethanes (THMs), haloacetic acids (HAAs), nitrosamines, and bromoform. DBPs are suspected carcinogens that may pose a potential threat to public health (Asano et al., 2007; Black and Veatch, 2010).

Advanced oxidation processes (AOPs) are becoming more popular due to their high removal rates and effectiveness (Aye et al., 2003; Asadi and Mehrvar, 2006; Venhuis and Mehrvar, 2005; Edalatmanesh et al., 2008; Oller et al., 2011; Poyatos et al., 2010). AOPs produce highly reactive intermediates, hydroxyl radicals ($^{\bullet}OH$), which are oxidant species twice as powerful as common oxidants such as chlorine or ozone. Processes such as UV/H_2O_2, which can cause direct breakage of H_2O_2, or vacuum-UV (VUV), which can cause direct homolysis of water, are capable of producing hydroxyl radicals. Hydroxyl radicals are able to quickly react with organic matter and chemical compounds in water causing their degradation. Moreover, AOPs are highly effective in disinfection processes for removing activating bacteria, viruses, and protozoa, while avoiding the production of toxic DBPs (U.S. EPA, 2006; Comninellis et al., 2008). Although the total cost for the complete mineralization of contaminants through AOPs is high, AOPs are usually combined with biological processes to lower total costs and improve the overall removal efficiency of organic matters (Tabrizi and Mehrvar, 2004; Lafi and Al-Qodah, 2006; Cao and Mehrvar, 2011; Oller et al., 2011).

In the present study, UV-C and VUV with wavelengths between 200–280 nm and 100–200 nm, respectively were tested for their effectiveness at reducing organic content and bacterial levels in synthetic wastewater. More specifically, VUV, UV-C, UV-C/H_2O_2, and VUV/H_2O_2 as well as their combinations were investigated in batch and continuous modes for the reduction of TOC and bacterial counts in secondary effluent of synthetic slaughterhouse wastewater at a laboratory scale.

2. Materials and methods

2.1. Materials

2.1.1. Bacteria strains

Four bacteria strains including *E. coli O157:H7* ATCC 700927, *Salmonella enterica* serovar Typhimurium ATCC 14028, *Shigella*