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Optimization of ozone disinfection and its effect on trihalomethanes

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ABSTRACT

Ozone is an attractive disinfection alternative to chlorine as chlorine has some environmental consequences due to its disinfection byproducts potential. In the present study ozone was used for the disinfection of secondary treated effluent of sewage treatment plant which is based on rotating biological contactor, process, Malaviya National Institute of Technology (Jaipur). From the experimental results it was found that ozone dose of 30 mg/L was required to achieve WHO standards for Total Coliform Count (TCC) of 1000 CFU/100 mL for food crop irrigation and recreational impoundments. One factorial design method of response surface methodology (RSM) was used for statistically obtaining optimum ozone dose that satisfies the norms for COD and TCC simultaneously. The optimized ozone dose suggested by the model was 30 mg/L to bring TCC within norms and the value of COD at this dose was 21 mg/L. Experimental verification of the results was in good agreement with the predicted results of one factorial design. Analysis of scanned electron microscopy (SEM) images, shows the effect of ozone doses on bacterial cell membrane. Effect of ozone on four trihalomethanes was also studied using GC–MS/MS.

1. Introduction

Wastewater reuse has become an attractive option for protecting the environment and natural water resources in many regions of the world, particularly in water scarce areas where competition for water is high [1]. It is important that adequately treated wastewater should be disinfected, as the main objective when using reclaimed water is consumer's health and environmental protection [2].

Disinfection is the mechanism for the removal or reduction of pathogenic organisms to prevent the spread of water-borne diseases [3]. Historically, chlorination was the most widely used disinfectant to deactivate pathogenic microorganisms in wastewater. But alternative technologies have to be evaluated because of increasingly concern over undesirable disinfection byproducts (DBPs) of chlorination and its inefficiency in eliminating some of the resistant microorganisms at low chlorine doses (CD) [4–6]. Due to this concern, recently, there is an increasing use of ozone in wastewater reclamation.

Ozone is an attractive disinfection alternative as it is a potent germicide and simultaneously oxidizes organic matter thereby improving the wastewater quality [2,7–11]. It is an exceptionally good disinfectant that has faster disinfection kinetics and is more potent to eliminate most microorganisms when compared with other widely used chemical disinfectants [2,7]. It has been reported that ozone disinfection is very effective for removal of total coliforms (TC) and chlorine resistant microbes including pathogens which are especially resistant to most other disinfectants [8]. The germicidal effect of ozone results in total or partial destruction of the cell wall, resulting in cell lysis. In addition to this, ozone also breaks chromosomes, nitrogen carbon bonds between sugar and bases, DNA hydrogen bonds, as well as phosphate sugar bonds leading to depolymerisation and leakage of cellular constituents [3]. Thus, overall it helps in achieving higher effluent quality and better physicochemical and microbiological quality standards before it is discharged [13]. As opposed to chlorine, ozone does not even leave any trace of the residual product upon its oxidative reaction [4,14] and also avoids the environmental consequences caused by chlorinated DBPs as no harmful byproducts are formed after ozonation [15,16].

Abbreviations: AC, alternate current; ANOVA, Analysis of Variance; APHA, American Public Health Association; BOD, Biological Oxygen Demand; CFU, Colony Forming Unit; COD, chemical oxygen demand; DBP, disinfection by product; DNA, deoxyribose nucleic acid; HAA, halo acetic acid; MNIT, Malaviya National Institute of Technology; MPN, most probable number; NTP, normal temperature and pressure; ppm, parts per million; RBC, Rotating Biological Contractor; RSM, Response Surface Methodology; SEM, scanned electron microscopy; TCC, Total Coliform Count; TOD, transferred ozone dose; THM, tri halo methane; USEPA, United States Environment Protection Agency; UV, ultra violet; WHO, World Health Organization.

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The concentration-time (CT) values associated with ozone are orders of magnitude lower than those associated with any other oxidant [17,18]. It has been reported that low ozone concentration and short contact times are sufficient for disinfection purposes [2–4,8,19]. The effectiveness of disinfection depends on the ozone dose, the quality of the effluent, the ozone demand and the transfer efficiency of the ozone system [12].

The present study was conducted to evaluate the effectiveness of ozone treatment on disinfection of secondary treated effluent of STP based on Rotating Biological Contractor (RBC) process, located at MNIT Jaipur, India. To prove the strong oxidising power of ozone, this study investigates the COD variation during the disinfection process. Its main focus is to find an optimum dosage of ozone for disinfection of secondary treated effluent for achieving the WHO [20] standards for irrigation and agriculture purpose, to avoid the excess dosing. At the same time, experiments were also carried out to find effective ozone dose for complete removal of pathogens. During these experiments, an effect of ozone on the physicochemical and biological characterization of effluent in semi-continuous process was recorded. This study also includes results of SEM analysis to demonstrate the bactericidal effect of different ozone doses to get a clue to its inactivation mechanism by analysing changes in the ultrastructure of microbes, including cell lysis.

Ozonation could change the structure of organic compounds in wastewater effluents, and one of the key challenges faced when using ozone as an oxidising agent is the formation of DBP compounds. The formation and control of DBPs in drinking water by pre-ozonation and post-chlorination has been reported [21–23], but little is known on that in wasterwater resue. Hence, the effects of ozonation on the formation of DBPs (mainly four common THMs) was studied with the help of GC–MS/MS.

In brief, this paper adds information to the literature available on ozone disinfection and its effect on DBPs. Effect of ozonation on DBPs in drinking water has been studied in detail, but little is known on wastewater reuse. Species wise analysis of microorganisms to optimize the disinfection process for wastewater is new by understanding the broad microbial changes as a response to ozonation. In fact, this study is a part of an ongoing comprehensive study on the hybrid process with chlorination followed by ozonation to optimize the overall process of disinfection of sewage. SEM micrographs were taken, and THM generation was monitored to compare this process with that of chlorination as well as the hybrid process described in the previous statement.

2. Materials and methods

The research work was carried out at PHE laboratory at Department of Civil Engineering at Malaviya National Institute of Technology (MNIT), Jaipur. All reagents and chemicals used were of analytical grade (Sigma Aldrich) with no interference. Stock standard solutions used were of high purity grade (Sigma products) to prepare the calibration curve.

2.1. Collection of effluent sample

The samples used in the current study were collected from the final outlet of the secondary clarifier of STP located in the, MNIT, Jaipur campus which receives domestic wastewater from the student hostels and staff residences. Collected samples were stored at low temperature (4 °C) in the dark. Physicochemical and microbiological analysis (as wastewater contains several pathogenic and nonpathogenic species) was carried out within one hour of sample collection.

2.2. Experimental setup and procedure

The entire ozonation system consisting of the ozone generator, ozone analyser and assessor units were housed in the well vented hood. Ozone generation rate was monitored with the help of "Anseros" made "OZOMAT GM-OEM", which is associated with ozone generator as shown in Fig. 1(a). Experiments were carried out in a 1000 mL capacity column glass reactor and the ozonation reactions were carried out in a batch process. The design parameters of reactor vessel are listed in Table 1.

A coarse bubble glass diffuser dispersed the air enriched with ozone at the bottom of the reactor due to which the water flowed counter current with the rising gas bubbles. A schematic sketch of the reactor set up is shown in Fig. 1(b).

Ozone gas was produced by passing oxygen between two electrodes bearing an AC potential under electrical corona discharge through a prominent ozone lab generator of Anseros made "OZOMAT COM" which is based on the principal of the "Corona Discharge". The gas flow was maintained at 50–100 NL/h and the concentration of ozone in the generated gas was measured by an online ultraviolet gas ozone analyzer (OZOMAT GM-OEM of ANSEROS, Germany). Ozone is formed by combining an oxygen atom with an oxygen molecule (O_2). This reaction is endothermic and requires a considerable input of energy [13]. When ozone decomposes in water, the free radicals such as hydrogen peroxy (HO_2) and hydroxyl ions (OH) are formed that have a great oxidizing capacity [24].

Knobs provided on the ozone generator (Fig. 1(a)) were adjusted to achieve the desired gas flow rate, system operating pressure and ozone generation rate. After the ozone generation rate has been stabilized (within 2 min) as indicated by the constant reading on the ozone monitor/analyser, the gas was introduced into the reactor and a stopwatch was turned on to keep track of the reaction period (1–5 min). Specific doses of ozone were injected and a total of 5 min of residence was allowed before drawing out samples for further microbial and COD analysis. The outgoing ozone in the exit gas stream from the reactor was estimated iodometrically by titrating the iodine liberated in the Potassium iodide (KI) traps (having absorbed ozone) using sodium thiosulphate ($Na_2S_2O_3$) to calculate the total consumption of ozone in the reactor [4]. Hence, total ozone dose transferred in the reactor per volume of sample (mg/L) was calculated by subtracting ozone concentration absorbed in iodine displacement in the outgoing gas stream of the reactor from the product of total ozone concentration applied in the reactor for a specific time.

Disinfection by ozone was carried out at different doses ranging from 15 to 42 mg/L to achieve the WHO standard for reusing treated wastewater. Different ozone doses were selected based on the literature review and preliminary experiments, as the ozone concentration ranging between 3–40 mg/L has been reported for the inactivation of total coliform [7]. The criteria for selection were, the minimum ozone dose that meets disinfection target of 1000 CFU/100 mL and the ozone dose that consistently meets the disinfection target and at lowest COD value

The progress of ozonation was monitored by estimating the effect of ozone dose on removal of microbes (which are naturally present in wastewater samples) through bacteriological analysis and residual concentration of COD.

2.3. Bacteriological analysis

Bacteriological analysis of the samples before and after disinfection was carried out using spread plate technique on specific growth media and also by the colilert 18-h method.