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Efficiency of Ozonation Disinfection in a Domestic Wastewater Treatment for Removing Existing Infectious Bacteria and Viruses and a Comparison with Chlorine Disinfection

Amir Hajiali[1], Gevorg P. Pirumyan[2]
[1]Postdoctoral Fellow at Yerevan State University (Center for Ecological Safety), Lecturer at Islamic Azad University (North Tehran Branch), Tehran, Iran, Email: a.hajiali.env@gmail.com
[2]Center for Ecological Safety; Head, Yerevan State University, Academician of the International Academy of Ecology and Russian Academy of Natural Sciences, Yerevan, Armenia, Email: gevorg_pirumyan@mail.ru

Abstract—*In this study disinfection of a domestic wastewater treatment plant was experimented in order to remove the infectious bacteria and viruses. For this purpose, ozone as a disinfectant was used whereas this wastewater used to be disinfected by the use of chlorine. Bacteria are microscopically small, single-cell creatures having a primitive structure. The bacteria body is sealed by a relatively solid-cell membrane. By ozonation, ozone interfered with the metabolism of bacterium-cells, most likely through inhibiting and blocking the operation of the enzymatic control system. A sufficient amount of ozone was used to break through the cell membrane, and this led to the destruction of the bacteria. Viruses are also small, independent particles, built of crystals and macromolecules, unlike bacteria they multiply only within the host cell. They transform protein of the host cell into proteins of their own. Ozone destroyed viruses by diffusing through the protein coat into the nucleic acid core, resulting in damage of the viral RNA (ribonucleic acid). Besides, at higher concentrations, ozone destroyed the exterior protein shell by oxidation so DNA (deoxyribonucleic acid) or RNA structures of the microorganism were affected. The results of the ozonation disinfection in comparison with the chlorine disinfection revealed a magnificent improvement in removal of the existing bacteria and viruses in the studied wastewater.*

Keywords— *Bacteria, Chlorine, Ozonation, Viruses, Wastewater Treatment.*

I. INTRODUCTION

Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of water-borne diseases to downstream users and the environment [1]. Furthermore, Disinfection of wastewater is one of the primary public health weapons used to avoid transmission of water-borne infectious diseases [2]. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective [3]. Chlorine seems to be relatively ineffective in eliminating viral pathogens; it also combines with other compounds during the disinfection process to form toxic by-products, a number of which are mutagenic and/or carcinogenic. These by-products are released into the aquatic environment and may have a deleterious effect on the autochthonous flora.

In view of results of several studies examining the safety of chlorination, many municipalities are wanting to remove chlorine from their water treatment plants all together. The cause for this concern is the presence of chloroforms and other halomethanes in post-chlorine treated natural water. The most commonly encountered contaminants of this type are bromomethanes CHClBr, CHClBr and CHBr along with the aforementioned chloroform all of which are suspected carcinogens. In view of these problems, alternative disinfecting agents, such as ozone and ultraviolet light was proposed. Of these, ozone appeared to be most suitable for wastewater disinfection. Ozone is a strong oxidant and virucide [4], [5]. The mechanism of disinfection using ozone includes:

- Direct oxidation/destruction of the cell wall with leakage of cellular constituents outside of the cell.
- Reactions with radical by-products of ozone decomposition
- Damage to the constituents of the nucleic acids (purines and pyrimidines)

When ozone decomposes in water, the free radicals hydrogen peroxy (HO_2) and Hydroxyl (OH) that are formed have great oxidizing capacity and play an active role in the disinfection process. It is generally believed that the bacteria are destroyed because of protoplasmic oxidation resulting in cell wall disintegration (cell lysis). The effectiveness of disinfection depends on the susceptibility of the target organism, the contact time, and the concentration of ozone [6]. The components of an ozone disinfection system include feed-gas preparation, ozone generation, ozone contacting, and ozone destruction [7].

Methods traditionally used for the evaluation of the efficacy of disinfectants or their effects on bacteria are based on the loss of culturability after exposure to the disinfecting agent. Direct count methods make it possible to obtain information about specific aspects of the physiology of the cells of a population. Ozone disinfection can generally be used at medium to large size plants after at least secondary treatment [8]. In addition to disinfection, another common use for ozone in wastewater treatment is odor control. Ozone treatment showed the ability to achieve higher levels of disinfection than either chlorine or UV, so it was chosen for

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this experiment [9]. However, the capital costs as well as maintenance expenditures were not competitive with available alternatives [10]. There are many different types of bacteria and viruses in domestic wastewaters. Table I lists some common micro-organisms found in the domestic wastewater and the diseases associated with them.

TABLE I. Infectious agents potentially present in the untreated domestic wastewater.

Organism	Disease Caused
Viruses	
Enteroviruses (72 types, e.g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A viruses	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis
Bacteria	
Esherichia coli(enterotoxigenic)	Gastrospirosis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2,100 serotypes)	Salmonellosis
Vibrio cholerae	Cholera

Wastewater should be disinfected in order to remove the mentioned bacteria and viruses so that it will be hygienic enough to be used for different purpose. This disinfection is a two part process that includes:

- Removal of particulate matter by filtration, because viruses and bacteria can hide within the rough texture of particulates. Therefore, removal of the particulates reduces the chance of pathogenic microorganisms in the effluent.
- Inactivation of pathogenic microorganisms by chlorine, chlorine dioxide, ozone, or other disinfectants like UV, that in this experiment ozone was chosen to be used and compare with chlorine in the same wastewater sample.

II. MATERIALS AND METHODS

Wastewater samples were collected after secondary treatment and before chlorination (common used method of disinfection) from a domestic wastewater treatment plant in Iran. Sterile wastewater sub-samples were prepared by filtering through 0·24 mm pore size membrane filters (Millipore) and autoclaving (127°C for 18min). The experiments were carried out under conditions in which both ozone and chlorine had an apparently similar efficacy, resulting in the same decrease in culturability of Esherichia Coli populations. The residual toxicity generated by disinfectants was also evaluated.

Ozone is produced when oxygen (O_2) molecules are associated by an energy source into oxygen atoms, and subsequently collide with an oxygen molecule to form an unstable gas, ozone (O_3), which then can be used to disinfect wastewater. Most wastewater treatment plants can generate ozone by imposing a high voltage alternating current (7 to 20 kilovolts) across a dielectric discharge gap that contains an oxygen-bearing gas [11]. Ozone should be generated onsite because it is unstable and decomposes to elemental oxygen in a short amount of time after generation [12].

Air or pure oxygen was used as the feed-gas source and was passed to the ozone generator at a set flow rate. The energy source for production was generated by electrical discharge in a gas that contained oxygen. The electrical discharge method is the most common energy source used to produce ozone. Extremely dry air or pure oxygen was exposed to a controlled, uniform high voltage discharge at a high or low frequency. The dew point of the feed gas must be -60 degree Celsius (-76 degree Fahrenheit) or lower. The gas stream generated from air contains about 0.6 to 3.1 % ozone by weight, whereas pure oxygen forms approximately two to four times that concentration.

After generation, ozone was fed into a down-flow contact chamber containing the wastewater to be disinfected. The main purpose of the contactor was to transfer ozone from the gas bubble into the bulk liquid while providing sufficient contact time for disinfection. The commonly used contactor type diffused bubble (co-current and counter current) were positive pressure injection, negative pressure (Venturi), mechanically agitated, and packed tower. Because ozone is consumed quickly, it must be contacted uniformly in a near plug flow contactor. Venturi Injectors work by forcing water through a conical body which initiates a pressure differential between the inlet and outlet ports. This creates a vacuum inside the injector body, which initiates ozone suction through the suction port. Air was being sucked into a injector. It is necessary to mention that the characteristics of Venturi are as followings:

- Very high ozone mass transfer rate (up to 90%)
- Requires water pump to initiate suction
- Efficiency rarely decreases over time
- No moving parts

Injectors produced thousands of bubbles greatly increasing the surface area of oxygen, or ozone, in contact with the water. (Two small bubbles had greater surface than one large bubble of the same volume). This resulted in a very high mass transfer rate.

It is critical that all ozone disinfection systems were pilot tested and calibrated prior to installation to ensure they meet discharge permit requirements for their practical sites.

The costs of ozone disinfection systems are dependent on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected [13]. Because the concentration of ozone generated from either air or oxygen is so low, the transfer efficiency to the liquid phase is a critical economic consideration [14]. For this reason, the contact chambers used can be usually cheap and covered. The annual operating costs for ozone disinfection include power consumption, and supplies, miscellaneous equipment repairs, and staffing requirements [15].

The key process control parameters are also dose, mixing, and contact time [16], [17]. An ozone disinfection system strives for the maximum solubility of ozone in wastewater, as disinfection depends on the transfer of ozone to the wastewater [18]. The amount of ozone that will dissolve in wastewater at a constant temperature is a functional of the partial pressure of gaseous ozone above the water or in the gas feed stream [19].

III. Results

In a comparison between ozone versus chlorine as disinfectants it was proven that based on 99.99% of bacterial concentration being killed and time taken, ozone was almost: 26 times of that of HOCl (Hypochlorous Acid), 2,540 times of that of OCl (Hypochlorite) and 4,950 times of that of NH_2Cl (Chloramine)

Furthermore, ozone performed at least 10 times stronger than chlorine as a disinfectant in this wastewater treatment. Chlorine reacted with meat forming highly toxic and carcinogen compounds called THMs or tri-halomethanes - rendering meats lesser quality products. THMs were also implicated as carcinogens in developing kidney, bladder, and colon cancers [20]. Chlorine also resulted in the production of chloroform, carbon tetrachloride, chloromethane besides THMs. On the other hand, ozone did not even leave any trace of residual product upon its oxidative reaction [21]. The destruction of specific existing bacteria and viruses by ozone in the studied domestic wastewater is seen in table II.

TABLE II. Destruction of specific existing bacteria and viruses by ozone in the studied domestic wastewater.

Pathogens	Dosage of Ozone
Bacillus Bacteria	Destroyed by 0.2 m/l within 29 seconds
Bacillus cereus	99% destruction after 5-min at 0.11 mg/l in water
Herpes Virus	Destroyed to zero level in less than 25 seconds with 0.1 to 0.75 mg/l.
Penicillium Bacteria	Ozone susceptible
Salmonella Bacteria	Very susceptible
Escherichia Coli Bacteria (from feces)	Destroyed by 0.23 mg/l within 29 seconds in air
E-coli (in clean water)	99.99% destruction at 0.26 mg/l for 1.8 minutes
E-coli (in wastewater)	99.9% destruction at 2.3 mg/l for 20 minutes
Bacillus Anthracis (causes anthrax in sheep, cattle and pigs. Also a human pathogen)	Ozone susceptible
Hepatitis A Virus	99.5% reduction at 0.27 mg/l for 2-seconds in a phosphate buffer
Influenza Virus	0.4 to 0.5 mg/l threshold value
Proteus Bacteria	Very susceptible
Diphtheria Pathogen	Destroyed by 1.5 to 2.2 mg/l
Enteric virus	95% destruction at 4.3 mg/l for 31 minutes in raw wastewater

A comparison of ozone versus chlorine used as disinfectants in wastewater treatment systems after the experiment is seen in the table III.

TABLE III. Comparison of ozonation vs. chlorination as disinfectants in the domestic wastewater treatment.

Action In Water	Chlorine	Ozone
Disinfection: Bacteria Viruses	 Moderate Moderate	 Excellent Excellent
Operation Hazards: Skin Toxicity Inhalation Toxicity	 High High	 Moderate High
Capital Cost	Low	High
Air Pre-treatment	None	Filer and dehumidify air
Oxidation Potential (Volts)	1.42	2.17
Environmentally Friendly	No	Yes
Carcinogen Formation	Likely	Unlikely
Micro flocculation	None	Moderate
Water Half-Life	2-3.5 hours	21 min.
Color Removal	Good	Excellent
Organics Oxidation	Moderate	High
pH Effect	Variable	Lowers
Complexity	Low	High
Monthly Use Cost	Moderate-High	Low

IV. Discussion

The efficacy of disinfectants is usually evaluated on the basis of decreases in culturable cells [22], [23]. Once the experiment done, it was found that after chlorination, the number of viable cells was higher than the count of culturable. The results obtained in this work accords with the formation of active but non-culturable *E. coli* cells after chlorination and ozonation. These results also suggested that in a situation where both disinfectants showed the same apparent efficacy, as measured by means of the decreases in *E. coli* culturability, their effect on the whole of the bacterial population was clearly different.

Ozone was over 2800 times faster to purify water and unlike chlorine, ozone left no harmful chlorinated by-products in the water and quickly reverted back to pure oxygen if it was unused [24]. Like other chemical water treatment systems chlorination disinfection left long-term chemical effects on the environment that some were negative, but ozone did not.

Ozone oxidized and also destroyed oils and other contaminants in water and could significantly reduce levels of harsh chemicals such as chlorine and their by-products and it acted as a micro-flocculent, aiding in the removal of minerals such as iron and manganese. Also this kind of disinfection qualities were not dependent on pH, nor did the addition of ozone effect the pH of water and was less corrosive than chlorine in water.

Ozone left no unpleasant chemical taste or smell and when it dissolved in water did not irritate skin, nose, or ears, nor did it dry out or leave a chemical film on skin. Ozone was generated on site and did not require storage and could not be over-dosed as unused ozone escapes out of the water and reverts to oxygen [25], [26].

Ozone was a stronger, faster, and commercially available disinfectant and oxidant for the domestic wastewater treatment and the ozone oxidation reactions took place several thousand times faster than those of chlorine for destruction of the bacteria, viruses, and most other organic and inorganic contaminants existing in this wastewater and in appropriate doses could treat all the water-borne pathogens, while chlorine could not (given practical, safe doses.)

V. Conclusion

The results indicated that ozonation could be more effective than chlorination for improving water quality. This is because after chlorination, detection of bacteria to grow on a culture medium could result in a serious over estimation of the real efficacy of disinfection due to the tendency of cells to aggregate as a consequence of the change in cell surface hydrophobicity. The toxicity bioassays are based on the effect of disinfectants on Photobacterium phosphoreum bioluminescence and have a direct application when predicting the effects on aquatic organisms. In this work, no relation between the toxicity values obtained for each disinfectant, the toxicity maintenance in the samples and the effect of the disinfectants on the E. coli cells was observed. Thus, after disinfection, chlorinated wastewater toxicity was significantly higher than ozonated wastewater toxicity (*P*_0·06); after 2 hours and 15 minutes toxicity was not detected in the ozonated samples while the toxicity of the chlorinated samples just decreased

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