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A review on sewage disinfection and need of improvement

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ABSTRACT

This paper presents a critical review on sewage disinfection process using chlorine, which is shrouded with lot of controversies. The review highlights the general applications and limitations of chlorination of sewage for disinfection including its low efficacy against resistant coliform bacteria that results in excess chlorine dosing. Excessive dose of chlorine is not only expensive, but it can also give rise to a series of DBPs many of which are proven carcinogens. Based on the results of the studies of our research group at MNIT, Jaipur, this paper explores as to how the chlorine doses can be optimized through step dosing and also how can the hybrid method of disinfection optimize the overall cost of desired level of disinfection. Combination of ozone in series with chlorine has been assessed for the possibility of reducing the overall disinfection cost and also at the same time getting rid of some of the carcinogenic DBPs of chlorination.

Keywords: Disinfection; Chlorination; Carcinogenic; DBPs

1. Introduction

India is facing acute water crisis with an ever growing population and as the demand outstrips the supply, which results in increased human exposure to wastewater discharged into the environment during the last two decades [1]. Conservation, watershed protection, and reclamation have become essential components of water management in the new millennium in order to meet the increasing demand [2]. Non-potable reuse of wastewater by the communities themselves for the applications such as irrigation, toilet flushing, industries is already widely practiced. Reuse of reclaimed water for potable purposes may be feasible after proper treatment and microbial reduction [3,4]. Primary, secondary, and even tertiary treatment cannot be expected to remove 100% of the incoming waste load, and as a result, many organisms still remain in the waste stream [5]. The conventional municipal sewage treatment plants, which generally do not include the disinfection process, reduce fecal microorganism's densities by 1–3 orders [6]. Thus, it becomes essential to develop an appropriate technology as to meet the standards in the receiving water bodies [4,7].

2. Sewage disinfection

Disinfection is the treatment of the effluent for the destruction or removal of all pathogens and microbes

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so that bacterial number is reduced to a safe level [5]. A variety of physical methods (UV, X-rays, etc.) or chemical methods (strong acids, alcohols, chlorine, ozone, etc.) are capable of destroying microorganisms [8]. The presence of *Escherichia coli* and total coliform is considered to indicate that fecal contamination of water has occurred [9]. Wastewater disinfection levels are determined by standards and recommendations that are specific to each country and region [10]. In general, these standards are becoming more and more stringent in order to ensure better health and environmental protection [11].

3. Sewage chlorination

Chlorination is a disinfection process that has been practiced for almost 100 years. Although the pros and cons of disinfection with chlorine have been extensively debated, it still remains the most widely used chemical for disinfection across the world [3,4]. Chlorine when added to wastewater rapidly hydrolyzes to hypochlorous acid according to the following equation [12]:

$$Cl_2 + H_2O = H^+ + Cl^- + HOCl$$

$$HOCl = H^+ + OCl^-$$

The two chemical species formed by chlorine during disinfection are hypochlorous acid (HOCl, electrically neutral) and hypochlorine ion (OCl^-, electrically negative), which are commonly referred to as "free available" chlorine [13]. Maintaining a predominance of HOCl is important due to the fact that pathogen surfaces naturally carry a negative electrical charge and are therefore more readily penetrated by the uncharged, electrically neutral HOCl than the negatively charged OCl^-, and HOCl is approximately 80 times more powerful as a disinfectant than OCl^- [11]. When chlorine is added to water, some of the chlorine reacts first with readily oxidizable substances such as Fe, Mn, H_2S, and organic materials and reduces most of it to chloride ion (the chlorine demand of the water). After meeting the immediate demand, the remaining chlorine concentration is called total chlorine which is further divided into: (1) The amount of chlorine that is reacted with compounds such as ammonia and nitrates is called combined chlorine and (2) the free chlorine, which is the chlorine available to inactivate disease-causing organisms, thus a measure to determine the potability of water [5,14]. The disinfection efficiency of the combined forms of chlorine is much lower when compared with free chlorine.

3.1. Advantages of chlorination

Chlorine is inexpensive, is an excellent bacterial disinfectant requiring short to moderate contact times, and its chemistry is very well understood. It has a very large established base, and its design and operating characteristics are well understood [11,13].

3.2. Limitations of chlorination and proposed modification in disinfection strategy

It has the main disadvantage of producing disinfection by-product, and to meet the standards, dechlorination technology is required to remove residual chlorine prior to discharge as even very low levels of chlorine residuals are toxic to aquatic life. This increases the cost of treatment by 20–30% [13]. The use of chlorine (Cl_2) as a water disinfectant has come under scrutiny because of its potential to react with NOM and form chlorinated DBPs [15,16]. Common disinfection by-products are trihalomethanes (THMs) and haloacetic acids (HAAs) [11,17]. Residual chlorine reacts with organic matter (humic acid and fulvic acid, present in soil) and forms DBPs [18]. Chlorine dose is the main factor affecting the type and concentration of DBPs formed [13]. Concerns over DBP exposures have increased associations between consumption of chlorinated water, and bladder cancer and adverse reproductive outcomes, including spontaneous abortion and low birth weight of babies [15,19]. Recent research has shown that effluent organic matter (EFOM) such as soluble microbial products which consist of macromolecules and cellular debris has also shown to be a source of precursors for a wide range of DBPs such as THMs, HAAs, HANs, and Nitrosamines. It has been reported that certain nitrogenous DBPs (HANs) and certain non-regulated carbonaceous DBPs (haloacetaldehydes) may be of greater health concern. These products in low (ng/l) level are associated with 10^{-6} lifetime cancer risk and are also toxic to aquatic organism [20,21]. Evidence has also shown that when saline sewage effluents are chlorinated bromide and iodide ions are oxidized to hypobromous acid and hypobromite, which could then react with organic matter in the sewage effluents to form brominated and iodinated DBPs. These Br-DBPs pose potential adverse effects on marine ecosystem and are more cytotoxic and genotoxic than their chlorinated analogs [22,23].

Recent studies [5,11,13] on the efficiency of chlorine disinfection on secondary treated sewage carried out using calcium hypochlorite against six genera *E. Coli*, *Klebsiella*, *Enterobacter*, *Pseudomonas*, *Hafnia*, and *Citrobacter* reported that two log-reductions were observed for most of the species in the first 5 min of contact. The subsequent 10 min were not found to be very effective. The period of 15–20 min of contact was again found effective for disinfection, probably signifying delayed disinfection due to the combined forms. A dose of 17.5 ppm in the form of calcium hypochlorite was required for disinfection to bring the total coliform counts to less than 1,000 per 100 ml, which is the desired USEPA standard [5]. But, the species-wise analysis indicated that while most of the coliform species could be brought below the norm at about 5 ppm of chlorine dose, in order to remove certain resistant species such as *Serratia/Hafnia* and *Enterobacter*, a high dose of 17.5 had to be given as shown in Fig. 1 [5].

As depicted in the Fig. 1 [5], while chlorine can act against most of the coliforms, its action against a few species leads to excessive dosing in order to comply with the existing coliform standards/norms. Two resistant varieties, namely *Serratia/Hafnia* and *Enterobacter*, required 17.5 ppm to attain the above norm as the reaction of chlorine with the carbohydrate and fatty acid present in these organisms is very slow [11]. It is quite likely that UV or ozone would be able to attack these species in a more efficient manner, and hence, a hybrid system can help optimize the overall disinfection process [13]. Excess chlorine dose can further lead to excessive THM formation [18].

In our studies [13], it was also found that the manner in which chlorine dose as a disinfectant is administrated in secondary treated wastewater also affects the disinfection efficiency. Dose of 5 ppm of chlorine at a single instance with 20 min of contact time was less effective than the step dose of 2.5 + 2.5 ppm at a time interval of 5 min and total contact time of 20 min. The reason attributed for this observation was derivation of the maximum benefit of free forms that are more effective than the combined forms of chlorine [24]. Minimization of chlorine dose can further reduce the formation of carcinogenic by-products [25,26].

Ozone is also used as a disinfectant in place of chlorine but not very popular as it is very reactive, corrosive, highly toxic, and uneconomical [24]. Ozone treatment has the ability to achieve higher levels of disinfection than either chlorine or UV; however, the capital cost and maintenance expenditures are not competitive with available alternatives. In drinking water, it does not form any residual thus cannot fight distribution system infections and thus cannot be used as secondary disinfectant. Ozone is therefore used only sparingly, primarily in special cases where alternatives are not effective. Ozone is also known to react with NOM to produce organic DBPs such as aldehyde and increase levels of assimilable organic carbon and with bromide ion to form bromated species [4].

In sewage disinfection, the same above properties of ozone can be exploited for benefit to reduce the total cost of disinfection by permitting it to react with chlorine-resistant organisms in a post-disinfection step to chlorination. Ozone is an efficacious antimicrobial oxidizer that when used in conjunction with low-dose chlorine notably improves water quality and clarity [4]. For disinfection and for oxidation of many organic and inorganic contaminants, the kinetics of ozone reactions are favorable. For many difficult compounds to oxidize such as organic compounds, for example, chloroform, the kinetics of ozone oxidation are slow and the ozonation in the presence of traces of hypochlorite ion can form inorganic by-products such as chlorate [24]. In the ozonation process, there are no harmful residuals that need to be removed because ozone decomposes rapidly and residual effect of disinfectant is not as much required in the case of sewage as it is used for bathing purpose, in agriculture, etc., that is, other than drinking purpose. Hence, combination of disinfectants such as chlorine and ozone is known to lead to greater inactivation when the disinfectants are added in series rather than individually. There are also benefits in dealing with a range of different types of pathogens of different sensitivities to

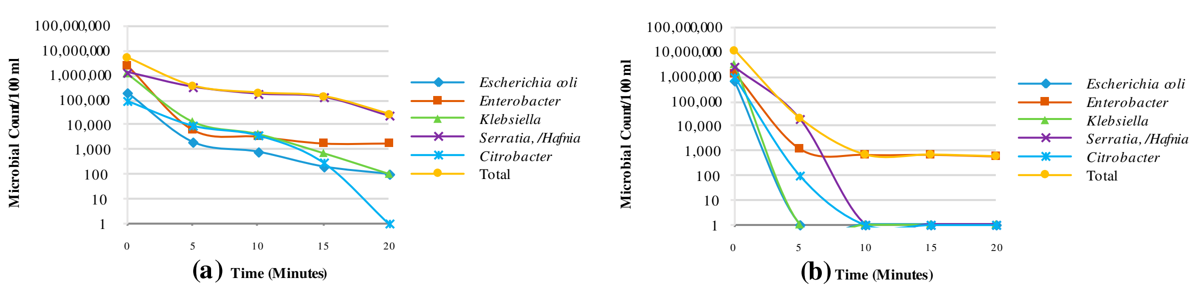

Fig. 1. (a) Coliform count removal profile for 5 ppm chlorine dose; (b) Coliform count removal profile for 17.5 ppm chlorine dose.

disinfection, and hence, a hybrid system can bring down the cost and at the same time would produce lesser DBPs of chlorination [8,13,25].

4. Conclusion and applicability

Chlorination is the most commonly used economical technology for disinfection of secondary treated sewage, but its limitations that it forms carcinogenic by-products due to high doses have forced researchers to devise new hybrid system to optimize the complete process. Development of a new hybrid disinfection strategy which can take care of chlorine-resistant coliforms as well as DBPs of chlorine can go a long way in mitigating serious environmental consequences associated with current practices of sewage chlorination. A combination of ozone in series with chlorine has been assessed an alternative for optimizing the overall sewage disinfection process as ozonation is a powerful oxidizing treatment of water. It kills many forms of bacteria and parasites which are resistant to conventional disinfectants (chlorination) on the other hand can minimizes the formation of DBPs such as THMs as chlorine doses will be reduced. Hence, ozone can ideally suit to serve as a secondary disinfectant in series with chlorine in sewage disinfection process to optimize the disinfection process.

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