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Evaluating the Use of Ozone for Disinfection of Drinking Water, Case Study: Tehran Pars Water Treatment Plant (Iran)

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Abstract
During recent years, surface water resources supplying Tehran's potable water – Karaj, Lar and Jajrood Rivers – are contaminated with different microorganisms due to population growth. Additionally, the amount of organic materials generating odor, taste and color in the surface water has increased sharply. By considering the trihalomethane (THM) production potential of dissolved chlorine in reaction with innocuous humic substances, future use of chlorine as a disinfectant in Tehran's drinking water is clouded in uncertainty. Accordingly, the use of ozone as another alternative was taken in to consideration for disinfection of drinking water in this mega city. In order to evaluate advantages and disadvantages of water ozonation a pilot with a generating capacity of 4 gr ozone per hour was designed. This study was performed between April and September 2005 and Tehran Pars water treatment plant in the Northeast of Tehran was chosen for the case study. Bacteria removal was considered to be at highest level in all monthly samples. Different ozone contact times and dosages were tested in the deactivation of nematodes and the results showed the perfect removal in specified periods. Although the initial investment for construction and implementation of the required apparatuses is relatively high, since the raw material for ozone generation is air, the use of ozone is financially justifiable during the predicted time of operation. Moreover, the transfer and storage of ozone is much easier in comparison with chlorine which is currently in use. Unlike chlorine, the use of ozone as a disinfectant does not have the potential of THMs generation. On the other hand, ozone must be generated on site and is instable in water. Therefore, a continuous and precise monitoring and maintenance process must be taken in to consideration. Furthermore, due to high corrosive potential of ozone, special resistant materials must be used in the applied instruments.

Keywords: ozone, water disinfection, Tehran Pars water treatment plant

ارزیابی استفاده از ازن در گندزدایی آب آشامیدنی مطالعه موردی: تصفیه‌خانه آب تهران پارس

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چکیده
طی سال‌های اخیر، به دلیل رشد جمعیت، رودخانه‌های کرج، لار و جاجرود به عنوان منابع آب سطحی تأمین کننده آب شرب تهران، با ریزجانداران گوناگونی آلوده شده‌اند. همچنین میزان مواد آلی مولد بود، طعم و رنگ در آب‌های سطحی افزایش چشم‌گیری داشته است. با توجه به پتاسنیل تولید تری هالو متان از واکنش کلرین محلول با مواد humic، استفاده موثر آتی از کلرین به عنوان ماده گندزدای آب آشامیدنی تهران در هاله‌ای از ابهام قرار می گیرد (با عدم قطعیت روبروست). از این‌رو، استفاده از ازن به عنوان گزینه‌ای دیگر برای گندزدایی آب آشامیدنی کلان شهر تهران مورد بررسی قرار گرفت. به منظور ارزیابی فواید و ضررهای ازن زنی آب، یک مورد آزمایشی با ظرفیت تولید ۴ گرم ازن در ساعت در نظر گرفته شد. این مطالعه در دوره زمانی فروردین تا شهریور ۱۳۸۴ انجام شد و تصفیه خانه تهران پارس در شمال شرقی تهران به عنوان مکان آزمایشی مطالعه انتخاب شد. به منظور انجام این مطالعه، بالاترین سطح حذب باکتری‌ها در همه نمونه‌های ماهیانه در نظر گرفته شد، زمان‌ها و غلظت‌های متفاوت ازن‌دهی در خنثی‌سازی نماتودها آزمایش شد و نتایج، حذف کامل باکتری‌ها در دوره‌های تعیین شده را نشان داد. با وجود این که سرمایه‌گذاری اولیه برای احداث و بهره‌برداری از دستگاه‌ها و تجهیزات مورد نیاز از جمله مواد خام برای تولید ازن در هوا نسبتاً بالاست، اما استفاده از ازن در طول زمان پیش‌بینی شده بهره‌برداری توجیه اقتصادی دارد. علاوه بر این، انتقال و ذخیره ازن نسبت به کلرین که در حال حاضر مورد استفاده قرار می گیرد، آسان‌تر است و استفاده از ازن در مقایسه با کلرین از پتانسیل تولید تری هالو متان کمتری برخوردار است. از سوی دیگر ازن باید در محل، تولید شود و از ثبات (ماندگاری) کمتری در آب برخوردار است و بنابراین اتخاذ فرایند نگهداری و پایش دقیق و مداوم ضروری است. علاوه بر موارد یادشده به دلیل پتانسیل خورندگی بالای ازن، باید موادی با مقاومت‌های ویژه در ابزار کاربردی استفاده شود.

کلیدواژه‌ها: گندزدایی آب، تصفیه خانه آب تهران پارس.

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Introduction

Globally, surface water and ground water are important sources for drinking water production (Heberer, 2002a; Heberer, 2002b; Hua *et al.*, 2006). Disinfection, one of the unavoidable stages in water treatment, is defined as the destruction of pathogenic microorganisms. It does not apply to non-pathogenic microorganisms or to pathogens that might be in the spore state (McCarthy and Smith, 1974). Chlorine is the most widely used disinfectant because it is effective at low concentrations, is cheap and forms a residual if applied in sufficient dosage. It may be applied as a gas or as a hypochlorite, the gas form being more common. The disinfecting ability of chlorine is due to its powerful oxidizing properties, which oxidize those enzymes of microbial cells that are essential to the cells' metabolic processes (Hammer and Hammer, 2004). Reaction of chlorine with innocuous humic substances results in the formation of trihalomethanes including chloroform, bromoform, bromodichloromethane and dibromochloromethane. These compounds are limited by drinking water regulations to a total of .1 miligram per liter because of tumorigenic properties (White, 1998). Conventional drinking water treatment processes such as coagulation/flocculation, filtration, and chlorination are largely ineffective in removing some specific pollutants (Ternes *et al.*, 2002; Verstraeten *et al.*, 2002). Ozone (O3) has traditionally been applied in drinking water treatment plants (WTPs) for disinfection and oxidation (e.g. decoloration, taste and odor control, elimination of micropollutants, etc.) (Von Gunten, 2003a; Hijnen *et al.*, 2001). However, the benefits of treatment by ozone are unfortunately accompanied by the oxidation of bromide to bromate which is classified as a potential human carcinogen (von Gunten, 2003b; Meunier *et al.*, 2006; Smeets *et al.*, 2006). Ozone is an allotrope of oxygen. It is a powerful oxidant and is more powerful than chlorine and other oxidants. In aqueous solution it is relatively unstable, having a half-life of 20 to 30 minutes at 20 degrees centigrade. The presence of oxidant-demanding materials in solution will render the half-life even shorter (Rice *et al.,* 1979).

Ozone is widely used in drinking water treatment practice in Europe, its first application having been in 1893 at Oudshoorn in The Netherlands. Today more than 1,000 plants throughout the world use ozone. Canada has 22 plants and Montreal has probably the world's largest (Rice *et al.*, 1979).

Ozone must be produced on-site because it can not be stored as chlorine can. This is not necessarily bad; serious accidents have happened with chlorine because of breaks in storage systems. Ozone is produced by passing air between oppositely charged plates or through tubes in which a core and the tube walls serve as the oppositely charged surfaces. Air is refrigerated to below the dew point to remove much of the atmospheric humidity and then is passed through desiccants such as silica gel, activated alumina to dry the air to a dew point of -40 to -60 degrees centigrade. The use of dry and clean air results in less frequent ozone generator maintenance, long-life units and more ozone production per unit of power used (Jolley, 1975).

Ozone sterilizes water and removes all microorganisms including microbes, viruses, amebas, etc. in a short period of time (Qasim *et al.*, 2002). Being a powerful oxidant, it oxidizes all humic compounds in addition to iron and manganese and consequently decreases water taste and odor completely and color up to 60%.

During recent years, surface water resources supplying Tehran's potable water – Karaj, Lar and Jajrood Rivers – have been contaminated with different microorganisms due to population growth. Additionally, the amount of organic materials generating odor, taste and color in surface water has been increasing sharply. By considering the THM production potential of dissolved chlorine in reaction with innocuous humic substances, future use of chlorine as a disinfectant in Tehran's drinking water is clouded in uncertainty. Accordingly, the use of ozone as another alternative was taken in to consideration for disinfection of drinking water in this city.

In this study the use of ozone as a water disinfectant is taken in to consideration for disinfection of drinking water in the mega city of Tehran.

Materials and Methods

In order to evaluate advantages and disadvantages of water ozonation a pilot with a generating capacity of 4 gr ozone per hour was designed. As ozone is in gas form and its addition to water in precise measures is so difficult in bench scale, the saturated solution of ozone in water was applied instead. Considering ozone instability in water, the pilot was designed in such a way that dissolved ozone is easily added to samples with no contact by atmosphere. A simplified schematic view of the pilot is given in Figure 1. The ozone generator pumps the ozone to a chamber having a volume of 4 liters. After being mixed with the entered ozone, the water sample is sent to a 6-liter reactor.

This study was performed between April and September 2005 and Tehran Pars water treatment plant was chosen for the case study. This water treatment plant is located in the Northeast of Tehran and its water supply is provided via the Lar and Jajrood Rivers. This water treatment plant has been used since 1983 and, currently, dissolved chlorine is used for disinfection in this treatment plant. Particularly .6 and 1 milligrams per liter is injected for pre-chlorination and chlorination respectively.

Results and Discussion

Sampling was carried out in order to evaluate the influence of ozone in the deactivation of bacteria and parameters like total coliforms in most probable number (MPN), fecal streptococci in MPN and heterotrophic bacteria in colony forming units per milliliter (CFU/ml) were measured in proportion to the amount and contact time of ozone. The results are shown in Table 1.

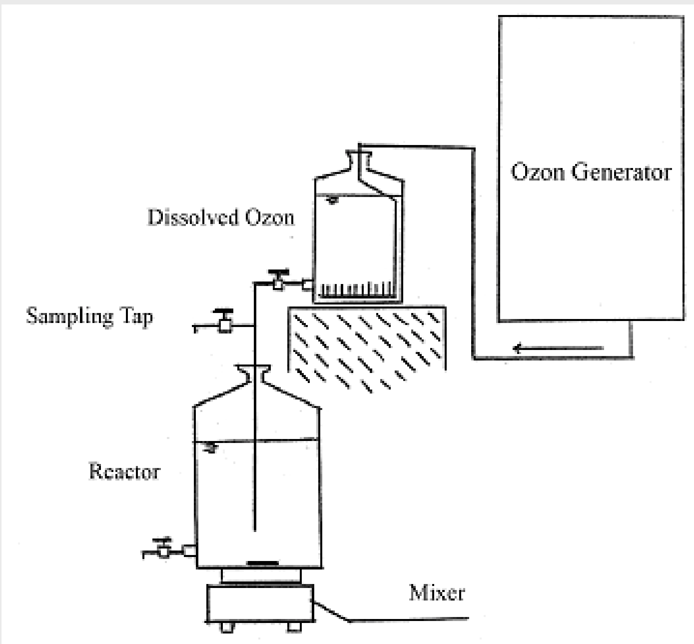

Figure1- Designed pilot for water ozonation

Table 1- Effect of ozone with concentration of 1 ppm in deactivation of different bacteria

Sample	Contact Time (Min)	Residual Ozon (ppm)	Total Coliform Bacteria (MPN/100ml)	Fecal Streptococci (MPN/100ml)	Heterotrophic Bacteria (CFU/ml)
Blank	----	----	>1600	900	>6500
1	4	.55	16.1	>1.1	>25
2	5	.4	2.2	>1.1	10
3	10	.3	1.1	>1.1	----
4	12	.3	1.1	>1.1	----

In Figures 2 to 5 the percentage of bacteria removed and residual ozone are illustrated for different amounts and contact times of ozone. As can be seen in these figures, bacteria removal is at its highest level in all cases.

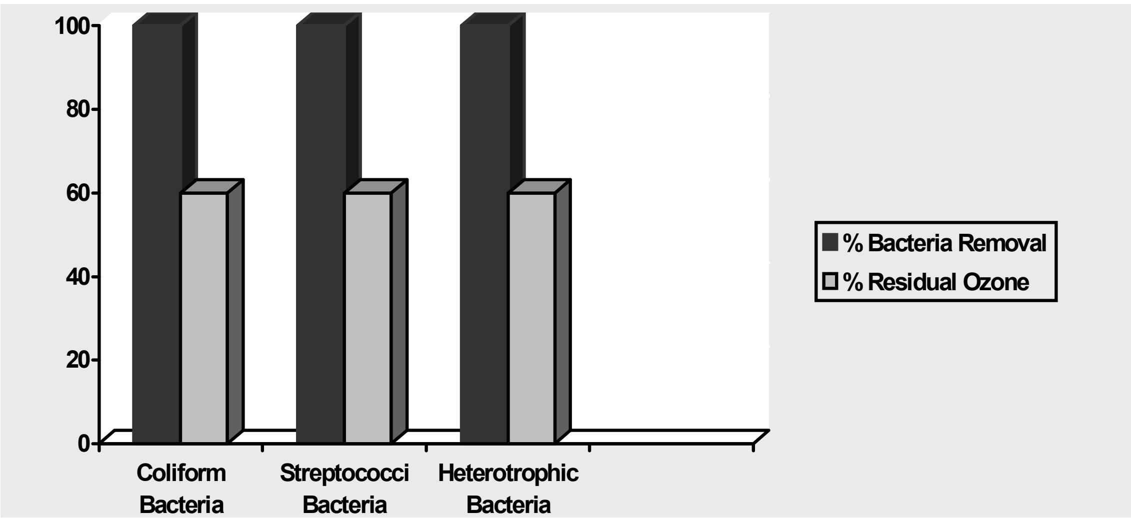

Figure 2- Percentage of bacteria removal in a 4-minute contact time and ozone concentration of 1 ppm

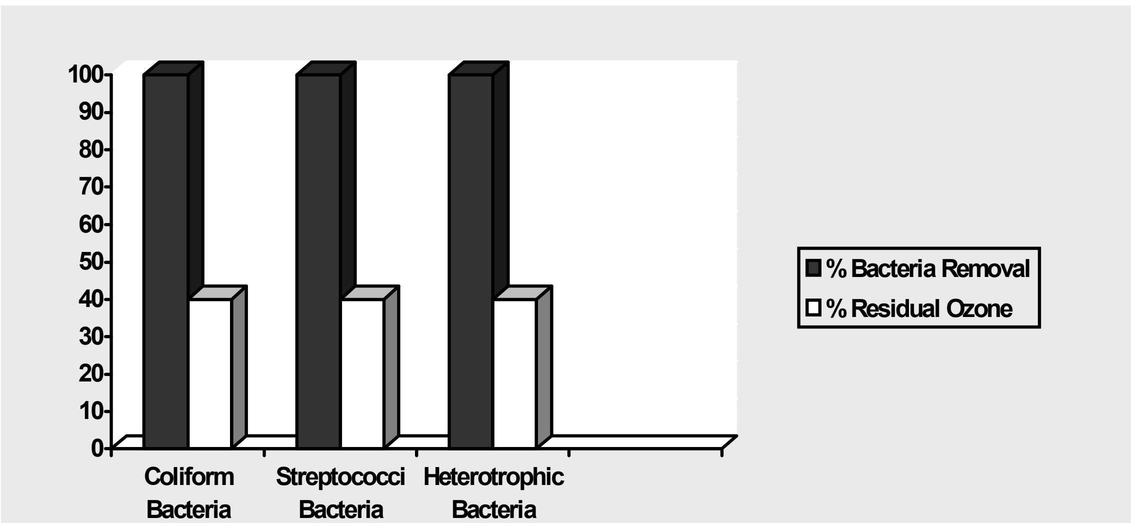

Figure 3- Percentage of bacteria removal in a 5-minute contact time and ozone concentration of 1 ppm

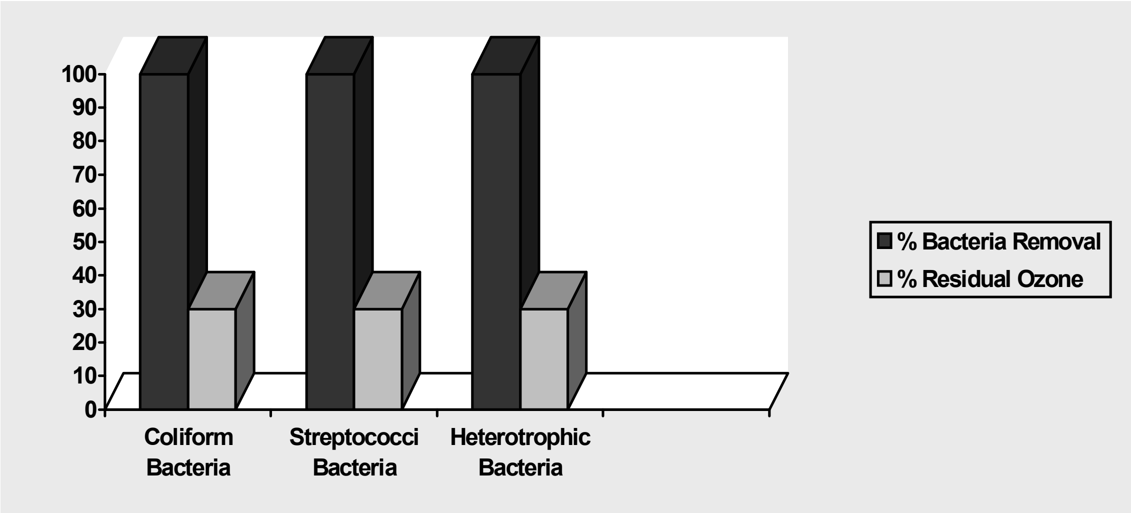

Figure 4- Percentage of bacteria removal in a 10-minute contact time and ozone concentration of 1 ppm

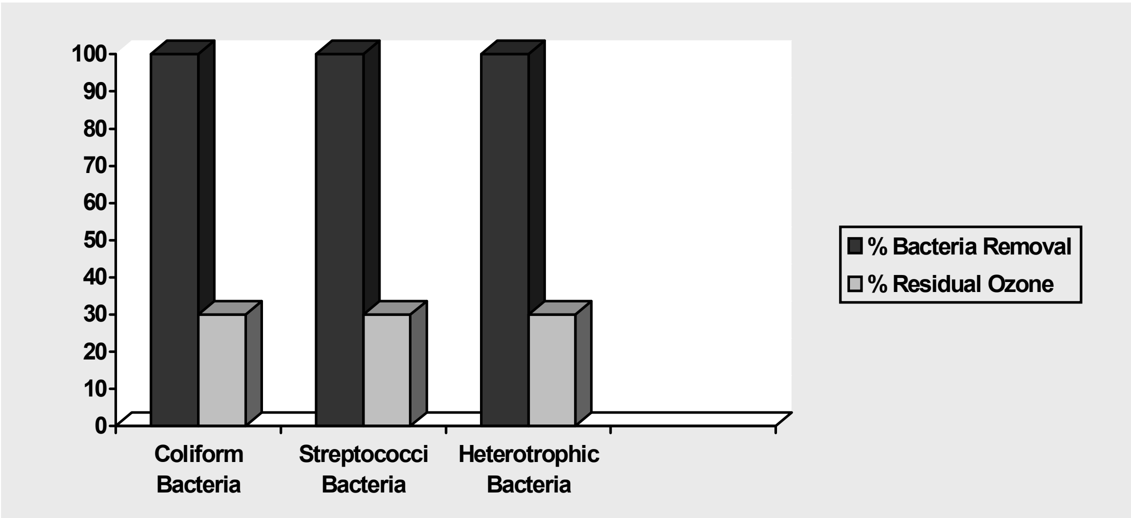

Figure 5- Percentage of bacteria removal in a 12-minute contact time and ozone concentration of 1 ppm

Nematodes are among the most tolerant microorganisms in water because of their coticoul membrane. Chlorine in low dosages is incapable of removing them. Accordingly, in evaluating the efficiency of ozone in water disinfection these microorganisms have been considered as indexes. Different ozone contact times and dosages were tested in deactivation of nematodes in the samples (6 liters) and the results are shown in Table2.

Formation of bromated compounds in water – which are considered to be carcinogenic – depends on many factors including initial concentration of bromide in water, pH, etc. Ozone is a major factor which reinforces the conversion of bromide to bromated compounds. Accordingly, the measurement of bromide and bromate was applied after a five-minute contact time of ozone which is a common period of time in ozonation. The results are given in Table 3. As is indicated, the concentration of bromate is more than the maximum contaminant level (MCL) entitled US EPA.

Table 2- Influence of ozone on nematode removal

Sample	Ozone concentration (ppm)	Ozone residual after 5 min (ppm)	Number of nematodes in samples	Number of living nematodes after ozonation	Number of dead nematodes after ozonation	Percentage of nematodes removal
Blank	0	0	286	286	0	0
1	2.5	.2	316	43	273	86
2	2.75	.5	257	7	250	97
3	3	.7	276	5	271	98
4	3.25	1.4	262	2	260	99
5	3.25	1.9	190	0	190	100

Table 3- Results of bromate generation as a consequence of ozonation

Sample	Date	pH	Turbidity (NTU)	T (ºC)	Bromide mg/l	Residual ozone after 5 min (mg/l)	Generated Bromate mg/l	Brom to Bromate conversion efficiency %
1	April	8.4	.6	23	.4	2	.25	39
2	July	8.2	1.5	24	.5	1.6	.35	44
3	Sept.	8.3	1.5	21	.5	.8	.36	45

Conclusion

Although the initial investment for construction and implementation of the required equipments is relatively high, since the raw material for ozone generation is air the use of ozone can be justified financially during the predicted time of operation. Moreover, transfer and storage of ozone is much easier in comparison with chlorine which is currently in use.

Unlike chlorine, use of ozone as a disinfectant does not have the potential of trihalomethanes (THMs) generation (Chang *et al.*, 1991). Additionally, in the case of MTBE existing in the water of an over-polluted city like Tehran, ozone has the potential for removing it.

On the other hand, ozone must be generated on-site and is unstable in water. Therefore, a continuous and precise monitoring and maintenance process must be taken in to consideration. Furthermore, due to the high corrosive potential of ozone, particular resistant materials must be used in applied instruments.

According to the data achieved, use of ozone as a disinfectant is extremely efficient in the removal of different kinds of bacteria including total coliforms, fecal streptococci and heterotrophic bacteria as well as nematodes. Similar results have been reported by different authors; Gomella and co-workers have also observed complete destruction of poliovirus samples in distilled water at a residual of .3 mg/ l at the end of 3 minutes of exposure to ozone. They then observed the same effectiveness when the viruses were suspended in Seine River water, and recommended the use of .4 mg/ l after a contact of four minutes (Cheremisinof, 2002). However, testing some shorter ozone contact times or even thinner concentrations of ozone is also suggested for further studies.

Use of ozone decreases sharply the required time for flocculation and coagulation. Furthermore, increasing the efficiency of filtration up to 50%, use of ozone decreases sludge generation rate in back wash of filters. The only limiting factor in the usage of ozone as a disinfectant in the Tehran Pars water treatment plant is the existence of bromide in feed water. Further studies are recommended by the authors for the determination of the bromated compounds formation potential of water ozonation in this plant.

It should be noted that there are uncertainties about the reaction of ozone with organic materials. Different researches have been directed toward identifying by-products of the reaction of ozone with organic materials. The formation of several persistent, potentially dangerous epoxies has been predicted by ozone reaction models. These by-products may have significant human health and environmental consequences that will influence the use of ozone for water disinfection.

As a future study, a cost-benefit research on the use of ozone and chlorine for disinfection of Tehran's drinking water in different water treatment plants is suggested. Additionally, a parallel study on the adverse effects of THMs and bromated compounds in drinking water of Tehran is also recommended.

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