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APPLICATION OF OZONATION IN DRINKING WATER DISINFECTION BASED ON AN ENVIRONMENTAL MANAGEMENT STRATEGY APPROACH USING SWOT METHOD

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ABSTRACT
The disinfecting process has been considered as one of the most important steps in drinking water treatment and improper attention to this process can caused a social disaster. Until now, different methods have been used for drinking water disinfection, such as using the ultra-violet light and adding ozone or chloride. Because of the water sources contaminations, especially in surface water which is in closer contact with different pollutants, adding chloride to water, generally applied all over the world, can cause some adverse impacts on the residential users such as the ones caused by chlorinated chemicals and Trihalomethanes as the secondary products. Regarding to high level of electrical energy consumption and considering resulted costs, this method have not been developed in Iran. This study aimed to explain the drinking water ozonation process opportunities and threats. Usage of ozone is a useful and effective method and could be resulted in high oxidizing property, not producing carcinogens and eliminating bacteria, viruses and other disease-causing elements. On the other hand mentioned method will process in shorter time in comparison with other water treatment methods. There are different techniques for the strategic management as a suitable tool to conduct related environmental management plan. The study management methodology is based on SWOT; so it describes the management functional strategies for ozonation as a suitable drinking water treatment method. Finally, using the QSPM matrix, the hierarchical priority of these strategies was defined. It seems quite important that for the implementation of this process, the foreign experiments in disinfecting drinking water be studied and some proper workforce be trained.

Key words: Ozone, water disinfection, environmental management, SWOT method

INTRODUCTION
Disinfection is the destruction of pathogenic microorganisms. It does not apply to nonpathogenic 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 concentration, 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 *et al.*, 2004). Dissolved chlorine will react with organic compounds, particularly unsaturated compounds. Two of the organo reactions are particularly important, those that result in chlorophenols and those that produce trihalomethanes. Chlorophenols formed from the reaction of chlorine with phenols, impart undesirable tastes and odors to water that are detectable at phenol concentrations less than one microgram per liter. 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 0.1 miligram per liter because of tumorigenic properties (White, 1998). Ozone is an allotrope of oxygen. It is a powerful oxidant and is more

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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 was in 1893 at Oudshoorn, Netherlands. Today more than 1000 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).
Gomella and co-workers observed complete destruction of poliovirus samples in distilled water at a residual of 0.3 mg/L at the end of 3 minutes of exposure. They then observed the same effectiveness when the viruses were suspended in Seine River water and recommended the use of 0.4 mg/L after a contact of 4 minutes. Usual French practice uses two contactors. In the first with a contact time of 8 to 12 min, the ozone demand is satisfied and a residual of 0.4 mg/L obtained. In the second, with a contact time of 4 to 8 min, the 0.4 mg/L residual is maintained (Cheremisinof, 2002). Ozone is never used as a terminal treatment because experience has shown that organisms can under certain circumstances proliferate in distribution systems, causing all types of problems. Hence, many European plants utilize the desirable residual action of chlorine as a terminal disinfectant, but the dose is very low, such as 0.1 to 0.3 mg/L. Sharp social, economical and industrial development in recent decades in Iran has caused major pollution in local water resources. Accordingly, conventional water treatment methods, including disinfection may not be able to provide the required certainty of drinking water, specially for large cities like Tehran. Use of ozone as an effective disinfectant is being considered in this study. Different opportunities, threats, strengths and weaknesses relating to water ozonation are also discussed.

MATERIALS AND METHODS

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 surface water has been increased 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 overwhelmed with 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 generation capacity of 4 gram 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. The simplified schematic view of the pilot is shown in Fig. 1.
This study was performed between April and September 2005 and Tehranpars water treatment plant was taken it to consideration as the case study. This water treatment plant is located in northeast of Tehran and its water supply is provided via Lar and Jajrood rivers. With total capacity of 4.5 cubic meter of water per hour, this water pertreatment plant is being used since 1983.Currently, dissolved chlorine is used for disinfection in this treatment plant. Particularly 0.6 and 1 milligram liter is injected for prechlorination and chlorination respectively. In this study the use

of ozone as a water disinfectant is analyzed through SWOT (Strengths, Weaknesses, Opportunities and Threats) method. First of all internal factors including strengths and weaknesses of this proposal followed by external factors including opportunities and threats are thoroughly analyzed.

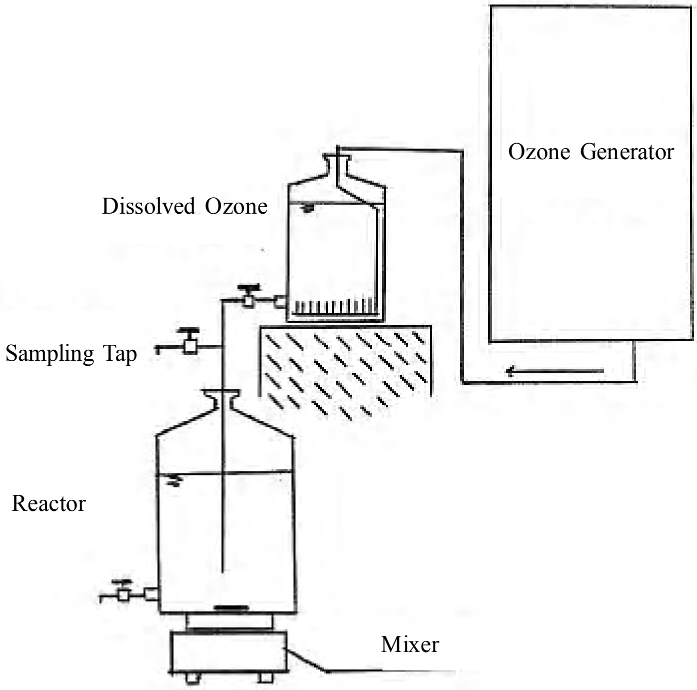

Fig. 1: Designed pilot for water ozonation

Considering all above aspects, some strategies are proposed for better implementation of the main target (water ozonation). Obviously, the strategy which has more strengths and opportunities and simultaneously less weaknesses and threats will be prior to others(Fahey and Naroyanan, 1983).

Consequently, the group of proposed strategies will be analyzed in a QSPM (Quantitative Strategic Planning Matrix) for being ordered. In this matrix the sorting of strategies is defined in following steps:

1) first of all, internal factors including strengths and opportunities as well as external factors including weaknesses and threats are taken in to consideration.

2) each factor is classified by contributing the grade 1, 2, 3 or 4 in accordance with it's effect on the considered strategy; grade 1 and grade 4 show the lowest and highest level of impact by the factor respectively.

3) different strategies are inserted in the matrix and a weight followed by a score is defined for each strategy.

4) the weight of each strategy in accordance with different internal and external factors varied between zero showing the lowest relationship and one showing the highest relationship. Finally, the sum of different weights relating to one strategy must equal one.

5) the score of each strategy in accordance with different factors is gained by the result of each factors grade multiplied by its weight.

6) finally, the total score of each strategy is computed and the final categorization would be applied according to the final scores. In other words, the strategy which has gained the most score will be proposed as the first option and so on (Thompson and Strickland, 1983).

RESULTS

Different strengths, weaknesses, opportunities and threats of the proposed option of using ozone in water disinfection in Tehranpars water treatment plant as well as different configurative steps of QSPM are shown in Tables 1, 2 and 3.

Strengths

- Powerful water sterilizer and microbial remover
- Oxidizing organic materials and reducing parameters like color, Mn, Fe,…
- Rapid disinfection
- No by-products generation (except for bromates)
- Low maintenance and operation costs
- Effective removal of water taste and odor
- No major problem in case of contingent over dosage
- Accessible and cheap raw material (Air)
- Increasing the filtration efficiency up to 50%
- Reduction of floc formation in flocculation and coagulation
- Less sludge volume generated from backwash process
- MTBE removal
- No THM generation
- No reverse environmental impact

Weaknesses

- Removal of useful water bacteria
- Pretreatment requirement in case of polluted raw waters
- Generation of hazardous by-products in case of brome existence in raw water
- Instability and low solubility in water
- High corrosion potential
- Need for precise monitoring and dosing adjustment
- Chronic hazards in case of being inhaled
- No efficiency in high temperatures

Threats

- It's expensive and needs lots of electricity
- Initial investment is remarkable
- Ozone generation system is complicated and needs specific technology
- The system needs sophisticated operational and maintenance considerations
- Current domestic water treatment plants are vulnerable encountering oxidation characteristic of ozone
- There is a remarkable lack of standard ozonation devices and instruments in Iran

Opportunities

- Acceptance of different organizations
- Existence of efficient and expert man power
- Economical aspects and financial provision
- Technological option and provision of required updated software and hardware
- Promotion of social hygienic level

Considering all above, following strategies are proposed in accordance with the use of ozone as a water disinfectant;

Environmental strategies considering the use of strengths for reducing threats

- Use of biological filters after ozonation in order to remove contingent generated by products.
- Sophisticated coagulation and flocculation in order to remove water turbidity before ozonation
- Implementation of training courses and consequently promotion of public awareness level in water consumption pattern
- Implementation of AMRS project in order to determine the current water consumption pattern in different hours of the day.

Environmental strategies considering the use of opportunities for reinforcing the strengths

- providing domestic expert man power in parallel with appropriate infrastructures for promotion of scientific and technological level in this field
- highlighting the role of private sector in domestic water and wastewater industry
- promotion of social awareness by means of training the managers of water and wastewater industry

Table 1- Reciprocal impacts of strengths and weaknesses, opportunities and threats relating to water ozonation according to SWOT method

External factors / Internal factors	Threats						Opportunities				
	It is expensive and needs lots of electricity	Initial investment is remarkable	Ozone generation system is complicated and needs …	The system needs sophisticated operational and …	Current domestic water treatment plants are vulnerable ..	There is a remarkable lack of standard ozonation …	Acceptance of different organizations	Existence of efficient and expert man power	Economical aspects and financial provision	Technological option and provision of required …	Promotion of social hygienic level
Strengths											
Powerful water sterilizer and microbial...	×	×	×	×	×	×	×	×	×	×	×
Oxidizing organic materials and …	×	×	×	×	×	×	×	×	×	×	×
Rapid disinfection	×	×	×	×	×	×	×	×	×	×	×
No by-products generation (except …	×	×	×	×	×	×	×	×	×	×	×
Low maintenance and operation costs							×		×		
Effective removal of water taste and odor	×	×	×	×	×	×	×	×	×	×	×
No major problem in case of contingent ..				×	×	×	×	×	×	×	×
Accessible and cheap raw material (Air)						×	×		×	×	
Increasing the filtration efficiency up …	×	×	×	×	×	×	×	×	×	×	×
Reduction of floc formation …	×	×	×	×	×	×	×	×	×	×	×
Less sludge volume generated from …	×	×	×	×	×	×	×	×	×	×	×
MTBE removal	×	×	×	×	×	×	×	×	×	×	×
No THM generation	×	×	×	×	×	×	×	×	×	×	×
No reverse environmental impact							×				×
Weaknesses											
Removal of useful water bacteria				×				×	×	×	
Pretreatment requirement in case of …	×	×		×				×	×	×	×
Generation of hazardous by-products …			×	×				×	×	×	
Instability and low solubility in water	×		×	×		×		×	×	×	
High corrosion potential	×		×	×				×	×	×	
Need for precise monitoring and dosing...			×	×				×	×	×	×
Chronic hazards in case of being inhaled				×				×	×	×	
No efficiency in high temperature			×	×				×	×	×	

Table 2: QSPM for determination of strategies (S1-S6) total score

Strengths	Grade	S1		S2		S3		S4		S5		S6	
		W	S	W	S	W	S	W	S	W	S	W	S
Powerful water sterilizer and microbial...	4	0.05	0.2	0.05	0.2	0	0	0	0	0	0	0	0
Oxidizing organic materials and …	3	0	0	0.05	0.15	0	0	0	0	0	0	0	0
Rapid disinfection	3	0	0	0.05	0.15	0	0	0	0	0	0	0	0
No by-products generation (except …	3	0.1	0.3	0.05	0.15	0	0	0	0	0	0	0	0
Low maintenance and operation costs	3	0	0	0.05	0.15	0	0	0	0	0	0	0	0
Effective removal of water taste and …	3	0.05	0.15	0.1	0.3	0	0	0	0	0	0	0	0
No major problem in case of contingent.	3	0	0	0	0	0	0	0	0	0	0	0	0
Accessible and cheap raw material (Air)	3	0	0	0	0	0	0	0	0	0	0	0	0
Increasing the filtration efficiency up …	3	0.05	0.15	0.05	0.15	0	0	0	0	0	0	0	0
Reduction of floc formation …	3	0	0	0.05	0.15	0	0	0	0	0	0	0	0
Less sludge volume generated from …	3	0.05	0.15	0.1	0.3	0	0	0	0	0	0	0	0
MTBE removal	3	0.05	0.15	0.05	0.15	0	0	0	0	0	0	0	0
No THM generation	3	0.05	0.15	0.05	0.15	0	0	0	0	0	0	0	0
No reverse environmental impact	3	0.05	0.15	0.05	0.15	0	0	0	0	0	0	0	0
Weaknesses													
Removal of useful water bacteria	1	0	0	0	0	0	0	0	0	0	0	0	0
Pretreatment requirement in case of …	2	0	0	0	0	0	0	0	0	0	0	0	0
Generation of hazardous by-products …	1	0	0	0	0	0	0	0	0	0	0	0	0
Instability and low solubility in water	1	0	0	0	0	0	0	0	0	0	0	0	0
High corrosion potential	1	0	0	0	0	0	0	0	0	0	0	0	0
Need for precise monitoring and…	2	0	0	0	0	0	0	0	0	0	0	0	0
Chronic hazards in case of being inhaled	1	0	0	0	0	0	0	0	0	0	0	0	0
No efficiency in high temperature	1	0	0	0	0	0	0	0	0	0	0	0	0
Opportunities													
Acceptance of different organizations	3	0	0	0.05	0.15	0.2	0.6	0.25	0.75	0.25	0.75	0.15	0.45
Existence of efficient and expert man …	4	0.05	0.2	0.05	0.2	0.2	0.8	0.15	0.6	0.2	0.8	0.25	1
Economical aspects and financial …	4	0.05	0.2	0.05	0.2	0.15	0.6	0.25	1	0.2	0.8	0.15	0.6
Technological option and provision …	4	0.05	0.2	0.05	0.2	0.2	0.8	0.2	0.8	0.15	0.6	0.25	1
Promotion of social hygienic level	4	0.05	0.2	0.05	0.2	0.15	0.6	0.1	0.4	0.1	0.4	0.15	0.6
Threats													
It is expensive and needs lots of …	1	0.05	0.05	0	0	0	0	0	0	0	0	0	0
Initial investment is remarkable …	1	0.05	0.05	0	0	0	0	0	0	0	0	0	0
Ozone generation system is complicate.	2	0.1	0.2	0	0	0	0	0	0	0	0	0	0
The system needs sophisticated …	2	0.05	0.1	0.05	0.1	0.1	0.2	0.05	0.1	0.1	0.2	0.1	0.2
Current domestic water treatment plants.	2	0.05	0.1	0	0	0	0	0	0	0	0	0	0
There is a remarkable lack of standard..	2	0.05	0.1	0	0	0	0	0	0	0	0	0	0
Total Score		1	2.65	1	3.25	1	3.6	1	3.65	1	3.55	1	3.85
Ranking			12		8		4		3		5		1

Environmental strategies considering minimization of disadvantages caused by threats and weaknesses

- Developing the current status of water treatment plants and providing required preparations for ozonation process
- Use of chlorination after ozonation in order to make sure of no microbial existence along distribution network
- Use of appropriate technology anf expert man power in order to monitor precise dosage of ozone in water and wastewater

Environmental strategies considering the use of opportunities for removing weaknesses

- Use of nonmetallic pipes in distribution networks in order to minimize corrosion hazard relating to ozone
- Implementation of research projects focusing on the use of ozone in water disinfection in other plants all around the country

Table 3: QSPM for determination of strategies (S7-S12) total score

Strengths	Grade	S7		S8		S9		S10		S11		S12	
		W	S	W	S	W	S	W	S	W	S	W	S
Powerful water sterilizer and microbial...	4	0.05	0.2	0.1	0.4	0	0	0	0	0	0	0	0
Oxidizing organic materials and …	3	0.05	0.2	0.05	0.2	0	0	0	0	0	0	0	0
Rapid disinfection	3	0.05	0.15	0.05	0.15	0	0	0.05	0.15	0	0	0	0
No by products generation (except …	3	0.05	0.15	0.05	0.15	0	0	0.05	0.15	0	0	0	0
Low maintenance and operation Costs	3	0.1	0.3	0.05	0.15	0	0	0	0	0	0	0	0
Effective removal of water taste and odor	3	0.05	0.15	0.05	0.15	0	0	0.05	0.15	0	0	0	0
No major problem in case of contingent..	3	0	0	0	0	0	0	0	0	0	0	0	0
Accessible and cheap raw material (Air)	3	0	0	0	0	0	0	0	0	0	0	0	0
Increasing the filtration efficiency up...	3	0.05	0.15	0	0	0	0	0	0	0	0	0	0
Reduction of floc formation …	3	0.05	0.15	0	0	0	0	0	0	0	0	0	0
Less sludge volume generated from …	3	0.05	0.15	0.05	0.15	0	0	0.05	0.15	0	0	0	0
MTBE removal	3	0.05	0.15	0	0	0	0	0	0	0	0	0	0
No THM generation	3	0.05	0.15	0	0	0	0	0	0	0	0	0	0
No reverse environmental impact	3	0	0	0.05	0.15	0	0	0.05	0.15	0	0	0	0
Weaknesses													
Removal of useful water bacteria	1	0	0	0	0	0	0	0	0	0	0	0	0
Pretreatment requirement in case of …	2	0.1	0.2	0	0	0	0	0	0	0	0	0	0
Generation of hazardous by products…	1	0	0	0	0	0	0	0	0	0	0	0	0
Instability and low solubility in water	1	0	0	0.15	0.15	0	0	0	0	0	0	0	0
High corrosion potential	1	0	0	0	0	0	0	0.2	0.2	0	0	0	0
Need for precise monitoring and dosing...	2	0	0	0.05	0.1	0.3	0.6	0	0	0	0	0	0
Chronic hazards in case of being inhaled	1	0	0	0	0	0	0	0	0	0	0	0	0
no efficiency in high temperature	1	0	0	0	0	0	0	0	0	0	0	0	0
Opportunities													
Acceptance of different organizations	3	0.05	0.15	0.05	0.15	0.1	0.3	0.1	0.3	0.22	0.66	0.3	0.9
Existence of efficient and expert man...	4	0.05	0.2	0.05	0.2	0.3	1.2	0.05	0.2	0.28	1.12	0.1	0.4
Economical aspects and financial …	4	0.05	0.2	0.05	0.2	0.15	0.6	0.05	0.2	0.07	0.28	0.3	1.2
Technological option and provision …	4	0.05	0.2	0.05	0.2	0.1	0.4	0.1	0.4	0.07	0.28	0.15	0.6
Promotion of social hygienic level	4	0.05	0.2	0.05	0.2	0.05	0.2	0.1	0.4	0.18	0.72	0.15	0.6
Threats													
It is expensive and needs lots of …	1	0	0	0	0	0	0	0	0	0	0	0	0
Initial investment is remarkable …	1	0	0	0	0	0	0	0	0	0	0	0	0
Ozone generation system is complicated..	2	0	0	0	0	0	0	0	0	0	0	0	0
The system needs sophisticated …	2	0.05	0.1	0.05	0.1	0	0	0.05	0.1	0	0	0	0
Current domestic water treatment plants..	2	0	0	0	0	0	0	0.05	0.1	0	0	0	0
There is a remarkable lack of standard …	2	0	0	0.05	0.1	0	0	0.05	0.1	0	0	0	0
Total Score		1	3.15	1	2.9	1	3.3	1	2.95	1	3.25	1	3.7
Ranking			9		11		6		10		7		2

DISCUSSION

According to the results achieved from Tables 1 and 2, the priority of 12 suggested strategies is determined as follows:

- highlighting the role of private sector in domestic water and wastewater industry

- implementation of research projects focusing on the use of ozone in water disinfection in other plants all around the country
- implementation of AMRS project in order to determine the current water consumption pattern in different hours of the day
- implementation of training courses and consequently promotion of public awareness level in water consumption pattern
- providing domestic expert man power in parallel with appropriate infrastructures for promotion of scientific and technological level in this field
- use of chlorination after ozonation in order to make sure of no microbial existence along distribution network
- use of nonmetallic pipes in distribution networks in order to minimize corrosion hazard relating to ozone
- sophisticated coagulation and flocculation in order to remove water turbidity before ozonation
- promotion of social awareness by means of training the managers of water and wastewater industry
- use of appropriate technology and expert man power in order to monitor precise dosage of ozone in water and wastewater
- developing the current status of water treatment plants and providing required preparations for ozonation process
- Use of biological filters after ozonation in order to remove contingent generated by-products.

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