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The Replacement of Chlorination in the Treatment of Municipal Drinking Water

By: Marianne Salama (9526822)

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ABSTRACT

This study has as its objective to determine which water treatment method is best suited to replace chlorination in the treatment of municipal drinking water. Chlorination has recently been shown to produce halomethanes in water which prove to be more hazardous to the health than the entities the chlorine was originally intended to destroy. In this light, the tendency is to move away from chlorination and replace it with a safer process. Among the processes analysed and compared are carbon filtration, ultra filtration, reverse osmosis, ultraviolet radiation, distillation, ozonation and ion exchange. The effectiveness of these in the removal of contaminants normally encountered in pre-treated municipal water are compared to that of chlorination. Capital and operational costs as well as the environmental impact of each solution was also taken into consideration. The conclusion of this research is that ozonation will result in the safest, cleanest drinking water supply.

ACKNOWLEGDEMENT

The author of this paper would like to thank the staff of OZOMAX LTD., situated in Granby, Quebec for having supported and encouraged me during this, my second summer working with them. In particular, I would like to thank Amir Salama, Director of Research and Development, for having taken me « under his wing » and taught me the basics of the fields of water treatment and ozone application engineering. The lessons which I learned from him are the foundation upon which this research has been built. I would also like to acknowledge Marie-Thérèse Makram, President, for having given me a second opportunity to work in a technology oriented company.

Established in 1991 OZOMAX LTD. specializes in the manufacturing of ozone generators as well as the engineering of ozone applications. The company objective is to remain at the forefront of ozone technology by continually renewing the paradigms of this field through the innovations of its Research and Development efforts. OZOMAX LTD. has exported its expertise worldwide to such countries as The United Sates of America, Mexico, Denmark, Italy, France, Holland, Egypt, Indonesia, Korea and China.

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INTRODUCTION

In the past the general belief in the realm of water treatment was that chlorination was the method of choice. It, after all, was capable of killing bacteria as well as some viruses which was and still is a major factor when evaluating a drinking water treatment process. But today, in view of recent 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 $CHCl_2Br$, $CHClBr_2$ and $CHBr_3$ along with the afore mentionned chloroform all of which are suspected carcinogens.

Instead of developing methods to remove the halomethanes produced by chlorination public officials, upon the advise of the scientific community, have opted to support the development and implementation of new, safer, more effective methods of water treatment. Among those available are filtration, distillation, ion exchange, reverse osmosis, ozonation, and ultraviolet radiation.

The objective of this study is to determine which method is best suited to safely treat municipal drinking water supplies. These methods will be compared to chlorination on their ability to kill bacteria as well as other commonly encountered contaminants found in pre-treated drinking water. Other points taken into consideration are their respective costs associated with the initial capital investment, operation, and maintenance.

SELECTION CRITERIA

The following criteria were considered to be important in the evaluation of the water treatment processes under scrutiny. Essential criteria are those which must be met by the process while desirable criteria are those whose fulfillment would be advantageous to the municipality but do not effect the acceptance of the process in the preliminary round of evaluation.

ESSENTIAL CRITERIA (Listed in order of importance)

As the actual carrying out of the experiments required to prove the following involve specialized equipment and resources the basis of their evaluation will be based on research found in literature. The term « removal » implies the conversion of the contaminant in question to a benign form or its precipitation and subsequent filtration through conventional media such as sand. Thus the studies performed must show conclusive results that prove that the process is capable of effectively attacking the pollutant and lowering its concentration to a level considered acceptable by the World Health Organization Water Norms (See Appendix A) from a level commonly found in pre-treated drinking water.

1. No Harmful By-Products

The treatment of water by the process must not result in the production of any substance that is harmful to the health.

This will be evaluated on a YES/NO basis.

2. Low Environmental Impact

The process should not further contribute to the pollution of the evironment by producing harmful residuals.

This will be evaluated on a LOW / MEDIUM / HIGH basis.

3. Disinfection of Water From Bacteria

The process must be known to kill all bacteria found in water.

This will be evaluated on a YES/NO basis.

4. Disinfection of Water From Viruses

The process must be able to kill viruses found in water.

This will be evaluated on a YES/NO basis.

5. Removal of Lead

The contamination of lake and river water with lead has been a prominant concern in the recent past. As lead has devastating effects on the nervous system and is a suspected carcinogen as well its removal from drinking water is essential.

This will be evaluated on a YES/NO basis.

6. Removal of Manganese

Commonly found in natural waters manganese as regulated by the World Health Association cannot exceed 0.05 ppm (See Appendix A).It is therefore important that the process be able to remove it.

This will be evaluated on a YES/NO basis.

7. Removal of Iron

Iron found in water stains bathtubs, toilets and sinks and is unfit for ingestion. The Hazardous Chemicals Desk Reference by Richard J. Lewis, Sr., lists it as a carcinogen.

This will be evaluated on a YES/NO basis.

8. Removal of Odour

Hydrogen Sulfide is commonly responsible for the « rotten egg » smell of some waters. As this is quite unpleasant and a prominant complaint of people claiming to have « bad water » its removal will be considered essential.

This will be evaluated on a YES/NO basis.

9. Removal of Colour

As clear water is more esthetically pleasing and will increase the public confidence in its water treatment plant the process must prove effective in the removal of color.

This will be evaluated on a YES/NO basis.

DESIRABLE CRITERIA (Listed in order of importance)

1. Lowest Relative Operational Cost

Although the lowest cost operation may not be capable of fulfilling the essential requirements listed above the process chosen will be that with the lowest relative operational cost among those which do meet all of the essential requirements.

As the actual process cost is a function of several variables mainly, the degree of pollution of the water to be treated, the flowrate required and the degree of automation desired it is difficult to calculate on a general basis and therefore the relative costs will be represented as either being LOW / MEDIUM / HIGH.

2. Lowest Relative Capital Investment

Obviously the lower the initial capital investment the easier it is to undertake and finance a project.

Again this criteria will be evaluated an a relative basis and denoted as LOW / MEDIUM / HIGH.

3. Low Maintenance

If the maintenance required is labour intensive the water treatment plant will become a financial burden. Therefore the process should be easy to maintain.

This will be evaluated on a LOW / MEDIUM / HIGH basis.

4. Simplicity of Process

If the process is too complex it will be difficult to troubleshoot should a system failure occur. This will entail a water shortage for the people of the municipality which would be a catastrophe. Therefore, the system should be as simple as possible.

The complexity of the process will be evaluated on a LOW / MEDIUM / HIGH basis.

5. Hardness Removal

Although hard water is not harnful to the health many people dislike having hard water as it increases their laundary, dishwasher and shower soap consumption. Therefore, it would be advantageous if the process chosen was capable of reducing water hardness.

This will be evaluated on a YES/NO basis.

<u>ALTERNATIVES</u>

The following lists and describes the most commonly used methods of water treatment. These will be compared and contrasted to determine which one would best replace chlorination in municipal water treatment as per their fulfillment of the essential and desirable criteria.

1. Activated Carbon Adsorption

Adsorption is a separation process by which aone or more components of a gas or liquid stream adheres to the surface of a solid adsorbent. The primary characteristic of an effective adsorbent is its large surface area due to its many fine pores whose total volume may comprise up to 50% of the volume of a particle. Adsorption is a physical process, also known as van der Waals adsorption, which occurs between the adsorbed molecules and the internal pore surface of the adsorbent particle. This phenomenon usually commonly occurs as a monolayer but several layers have also been observed. The overall process occurs in three steps as follows: 1) Diffusion of solute from the bulk to the surface of the particle, 2) Diffusion of the solute fom the surface of the particle to its internal pore structure 3) Adorption of the solute to the pore surface

This is a readily reversible process. All that is required is a « backwash » which removes what was adsorbed to the particle surface by washing them with clean, treated, pressurized water free of adsorbates.

Activated carbon is a microcrystalline adsorbent produced by the thermal decomposition of organic based materials such as wood, vegetable shells, and coal. Its surface area ranges from 300 to 1200 m^2/g with an average pore size of 10 to 60 Å.

2. Ion Exchange

Ion exchange media are insoluable granular solids whose molecular structures include exchangeable acid or base radicals. The loss of these radicals for others of the same polarity contained in the liquid in contact with them does not entail any deterioration , solubilization nor modification to the physical appearance of the solids.

This process may be represented by the following reversible reactions,

a) $Ca^{2+} + Na_2R \leftrightarrow CaR + 2Na^+$

b) $Na^+ + HR \leftrightarrow NaR + H^+$

c) $Cl^- + RNH_3OH \leftrightarrow RNH_3Cl + OH^-$

Reaction (a) represents the basis of « water softening » wherein naturally occuring porous sands known as zeolites are used as cation-exchangers. Regeneration is carried out using LeChatelier's principle by « washing » the zeolites with salt solution thereby driving the reaction to the left.

Presently, the most commonly used type of ion-exchanger is made of synthetic resin or polymer containing sulfonic, carboxylic or phenolic groups. Cations are exchanged at these anionic groups as shown in Reaction (b). Alternatively, anions may be exchanged at amine sites as shown by Reaction (c).

3. Distillation

Adequate separation of a liquid mixture is achieved through distillation when the compositions of the vapour phase and the liquid phase differ greatly at equilibrium. The vapour phase is produced by heating the raw liquid solution to its boiling point. Although distillation is primarily concerned with the separation of components by exploiting their differing volatilities dissolved solids such as salts would remain in the bottoms thus separating them from the distillate, or vapour phase.

4. Reverse Osmosis

Membranes used in separation processes allow the passage of certain molecules while excluding others. In the osmosis of a salt water solution, for example, water will diffuse across a semi-permeable membrane from a dilute salt solution to a more concentrated solution. Equilibrium is reached when the amount of solvent passing through the membrane in opposite directions is equal. This gives rise to an osmotic pressure on the more concentrated salt water side and is represented by p in Figure 1(b). The properties of the solution and not of the semipermeable membrane determine the value of the osmotic pressure. By applying a pressure greater than the osmotic pressure on the concentrated solution side the flow of water is reversed thus extracting fresh water from the concentrated salt solution.

Unlike distillation, reverse osmosis can operate at ambient temperature without enducing phase changes thus reducing operational costs.

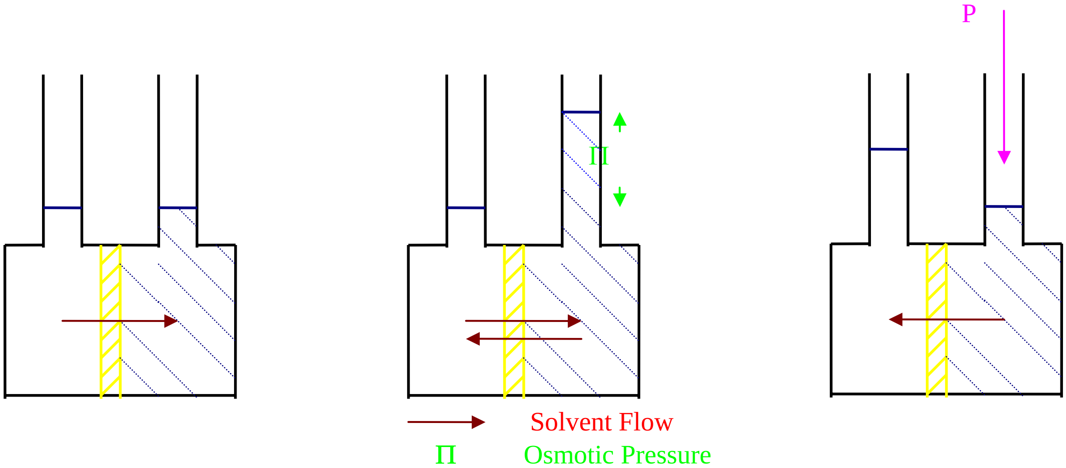

Figure 1. Osmosis and Reverse Osmosis

5. Ultrafiltration

Like reverse osmosis ultrafiltration is a membrane process. Large molecules are separated from a solvent the latter of which is collected in the permeate. This proces is often carried out in a filter press where pressure is used to drive the solvent through the membrane. As sown in Figure. A1 in Appendix A ultrafiltration may be used to capture solutes having molecular weights ranging from 500 to 1 000 000 or greater. Proteins, polymers, starches, colloidal dispersions and microorganisms fall within this range.

6. Ultraviolet Disinfection

Produced by very low pressure mercury vapour lamps, ultraviolet rays may be used to disinfect water. Bacteria as well as some viruses are irradiated and thus killed as the water flows as a thin stream through a pipe at the center of which runs a quartz tube containing a u.v. lamp. In order to achieve optimum results the raw water should be clear, colourless, odourless, free of turbidity, and must not contain any iron, organic colloids or planktonic microorganisms which are likely to deposit on the pipes, reducing the radiation transfer.

7. Ozonation

Ozonation is the process by which ozone is used as an oxidizing agent, in this case, to disinfect water. Ozone may be obtained by passing oxygen through a high energy field wherein the double bond of some of the oxygen molecules is severed resulting in the formation of atomic oxygen which inturn recombines with the molecules still intact forming ozone. This process is summarized by the following reactions,

$$O_2 + \text{Energy} \rightarrow 2O$$
$$O_2 + O \rightarrow O_3$$

The energy required to form ozone is most commonly supplied in the form of an electrical arc or ultraviolet radiation. Once formed, ozone acts as a powerful oxidizing agent second only to fluorine. This property has led to its extensive use in the field of water treatment.

Organic contaminats are converted to oxygen and carbon dioxide while metals are precipitated and subsequently filtered using sand or general filtration media such as AG. Excess ozone may be catalytically destroyed or vented to the outside depending on the location of the plant and local regulations. In both cases ozone breaks down to oxygen.

8. Chlorination

Chlorine has been widely used to disinfect drinking water supplies and therefore its attributes will also be examined. This process usually effectively rids water of unpleasant tastes and odours but has been recently been shown to produce halomethanes which are extreme health hazards.

ANALYSIS OF ALTERNATIVES

The following comparative analysis table summarizes the results of this research.

Table 1. Comparative Analysis of Municipal Drinking Water Treatment Methods

Criteria	Carbon Adsorption	Ion Exchange	Distillation	Reverse Osmosis	Ultra-Filtration	U.V. Radiation	O_3ation	Cl_2ation

ESSENTIAL								
Harmful By-Products	NO	NO	NO	NO	NO	NO	NO	YES
Enviro. Impact	LOW	LOW	MED	LOW	LOW	LOW	LOW	HIGH
Bacteria Removal	NO	NO	NO	YES	YES	SOME	YES	YES
Virus Removal	NO	NO	NO	YES	YES	NO	YES	SOME
Lead Removal	SOME	SOME	YES	YES	NO	NO	YES	NO
Manganese Removal	SOME	YES	YES	YES	NO	NO	YES	NO
Iron Removal	NO	SOME	YES	YES	NO	NO	YES	YES
Odour Removal	YES	NO	SOME	YES	SOME	NO	YES	YES
Colour Removal	YES	YES	YES	YES	SOME	NO	YES	SOME
DESIRABLE								
Op. Cost	V. HIGH	MED	V. HIGH	MED	MED	MED	LOW	MED
Capital Cost	MED	MED	HIGH	V.HIGH	HIGH	MED	HIGH	MED
Maintenance	HIGH	MED	MED	HIGH	HIGH	HIGH	MED	MED
Complexity	LOW	HIGH	LOW	HIGH	MED	MED	MED	MED
Hardness Removal	NO	YES	YES	YES	SOME	NO	SOME	NO

The water treatment processes fulfilling all of the essential criteria (as shown in red above) are:

1) Reverse Osmosis

2) Ozonation

Comparing these two on the basis of the desirable criteria it can be seen that ozonation is the treatment process of choice. Its low relative operational cost as well as its lower maintenance demand makes it an attractive, safer alternative to chlorination. The simplicity of the process layout will also decrease maintenace crew training time as well as repair time which ultimately equates to lower labour expenses and high public satisfaction. Although reverse osmosis is capable of removing hardness from water this advantage is not important enough to justify the higher capital cost, maintenance cost and the training cost required to familarize the maintenance team with this more complex system. Also, residential water softeners are readily available on the market and affordable to the average person.

CONCLUSION AND RECOMMENDATIONS

As chlorinated water has been shown to contain harmful halomethanes an effort is presently being made to eliminate chlorination from municipal drinking water treatment plants. This research has found ozonation to be the alternative of choice as due to its capability of removing bacteria, viruses, colour, odour as well as various metals from water. Most importantly it is environmentally friendly as ozone is produced an destroyed on site and is released as oxygen to the atmosphere. It is a simple process requiring an average amount of maintenance and entails low operating costs. It is therefore recommended that chlorination be replaced by ozonation in the treatment of municipal drinking water.

POTENTIAL PROBLEM ANALYSIS

Safety in the work place is, as it should be, an important concern today. As ozone is considered to be a hazardous substance (See Appendix B for its Material Safety Data Sheet) the treatment line will have to be equipped with alarms that will sound or automatically shut-down the ozone generator should a leak develop. According to OZOMAX LTD. engineers this is common practice in any ozone process. They also add that it is standard practise to have controllers that automatically shut-down the ozonator should the air compressor fail and that automatically adjust the ozone dosage according the the incoming water analysis. This is required as the water properties vary.

As the ozonator is an integral process to the process care must be taken when choosing the supplier. Their location as well as the quality of their technical support should be examined cosely. The availability of spare parts and the simiplicity of their installation is important. The ozonator injection system must be able to transfer a significant portion of the ozone produced in air to the water both for safety and economical reasons.

Above all, the ozonator capacity should be easily expandable in order to accomodate the growth of the municipality.

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Appendix A

TABLE A1. WORLD HEALTH ORGANIZATION

Drinking Water Norms

PARAMETER	NORM
Color	< 15 ucv
pH	6.5 - 9.5
Iron	< 0.3 ppm
Manganese	< 0.05 ppm
Nickel	< 1.00 ppm
Copper	< 1.00 ppm
Cobalt	< 1.00 ppm
Lead	< 0.05 ppm
Silver	< 0.05 ppm
Arsenic	< 0.05 ppm
Baryum	< 1.00 ppm
Boron	< 5.00 ppm
Cadmium	< 0.005 ppm
Calcium	200 ppm
Magnesium	150 ppm
Chromium	< 0.05 ppm
Selenium	< 0.01 ppm
Sodium	270 ppm
Sulfur	0.05 ppm
Mercury	0.001 ppm
Chlorides	250 ppm
Fluorides	< 1.5 ppm
Fecal Coliforms/100 mL	0
Total Coliforms/100 mL	0
Streptococcus	0

Appendix B

AUTHOR: Marianne Salama
STUDENT NUMBER: 9526822
DATE: September 22, 1997

ABSTRACT

This study has as its objective to determine which water treatment method is best suited to replace chlorination in the treatment of municipal drinking water. Chlorination has recently been shown to produce halomethanes in water which prove to be more hazardous to the health than the entities the chlorine was originally intended to destroy. In this light, the tendency is to move away from chlorination and replace it with a safer process. Among the processes analysed and compared are carbon filtration, ultra filtration, reverse osmosis, ultraviolet radiation, distillation, ozonation and ion exchange. The effectiveness of these in the removal of contaminants normally encountered in pre-treated municipal water are compared to that of chlorination. Capital and operational costs as well as the environmental impact of each solution was also taken into consideration. The conclusion of this research is that ozonation will result in the safest, cleanest drinking water supply.