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REVIEW ARTICLE

Impacts of Substituting Aluminum-Based Coagulants in Drinking Water Treatment

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Aluminum-based coagulants in drinking water treatment are widely used across Canada. According to the literature, the presence of aluminum in drinking water poses possible risks to humans. Preliminary studies investigating the use of alternative coagulating agents such as iron-based coagulants, lanthanide salts and organic coagulants have already revealed that their implementation is possible, but require further studies concerning their technical, economical, social and environmental impacts. The identified alternative coagulants need on-site studies, operator formation and/or further research and development for their industrial utilization and the production of safe drinking water.

Key words: **drinking water, aluminum-based coagulants, iron-based coagulants, alternative coagulants, organic coagulant, lanthanides**

Introduction

Orally ingested aluminum is acutely toxic to humans despite the widespread occurrence of this element in foods, drinking water and many antacid preparations (WHO 1998). It has been hypothesized that aluminum exposure is a risk factor for the onset of Alzheimer's disease in humans (WHO 1998). The degree of aluminum absorption depends on a number of parameters such as the aluminum salt administered, pH (for aluminum speciation and solubility), bioavailability and dietary factors (WHO 1998). Water treated with aluminum salts contain forms of soluble aluminum, which is a prevalent bioavailable source ingested by humans (Health Canada 1996). In order to reduce its presence in drinking water, Health Canada (1996) considers that the use of alternative coagulants or alternative treatment processes must be considered although the substitution of one coagulant or treatment process for another should be undertaken only after the safety and effectiveness of the substitute have been thoroughly studied. This consideration is important since Health Canada and Environment Canada (2000) are conducting many studies linking drinking water, aluminum ingestion and Alzheimer's disease.

In this study, the evaluation of different coagulant substitutes capable of replacing aluminum-based coagulants for water treatment in Canada was conducted. The different alternative coagulants available were evaluated according to the literature, to commercial suppliers and their possible use in water treatment. Alternative treatments and options in the clarification process are also studied. Different water producers were contacted to discuss their experiences and their perception related to the use of alternative coagulants. Technical, economical, social and environmental impacts have been identified and, when possible, evaluated.

Importance of Coagulants in Water Treatment

In North America, both local and national governments recommend the use of optimized coagulation, flocculation and sedimentation as the best available technology to treat surface water by removing organic matter, turbidity, pathogens, and to control chlorination by-product formations (U.S. EPA 1998; MENVQ 2002). Although membrane filtration is also considered the best technology available to treat surface water, its implementation requires studies and government approval (U.S. EPA 1998; MENVQ 2002). These treatment studies are necessary to evaluate different membrane efficiencies and costs. The capital cost of dual membranes (implementation and membrane changes), which may be used as clarification to remove particulate matter and organic substances, may double the production cost of drinking water (Najm and Trussel 1999). Membranes are more affordable when used in small communities (CSWSS 1997) and are recommended for the treatment of good quality surface water (MENVQ 2002). Considering the aforementioned complexities involved in membrane technology, coagulation,

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flocculation and sedimentation are widely used across Canada to treat surface waters.

Aluminum salts are widely used in surface water treatment as coagulants to reduce organic matter, colour, turbidity and microorganism levels (WHO 1998). In Canada, a large proportion of drinking water treatment plants use aluminum-based coagulants for their clarification treatment. According to Eaglebrook, which is a large coagulant supplier selling aluminum and iron-based coagulants in Canada (Eaglebrook, pers. comm.), 97.2% of their Canadian clients purify drinking water using aluminum-based coagulants.

Coagulants Used to Treat Drinking Water

Analyzing different experiments conducted using coagulation-flocculation processes allowed identifying potential products that may be used as coagulants for water treatment, some of which are widely available (aluminum and iron-based coagulants) and others are experimental coagulants. According to the literature, the performance of each coagulant fluctuates according to the type of water being treated.

Availability of Coagulants

Amongst all commercial coagulants, aluminum and iron-based ones are widely available and are most commonly used for water treatment (AWWA and ASCE 1990). The most common aluminum and iron salts utilized are: aluminum sulphate (alum), aluminum chloride, ferric sulphate and ferric chloride. Their complex forms (pre-hydrolyzed or pre-polymerized salts) commonly available are: poly aluminum sulphate (PAS), poly aluminum silicate sulphate (PASS), poly aluminum chloride (PAC), pre-hydrolyzed alum, hydroxylated ferric sulphate, poly ferric sulphate and poly ferric chloride. Coagulants are often used in conjunction with flocculant aids in order to improve clarification efficiency (AWWA and ASCE 1990).

Aluminum-Based Coagulants

Compared to others, the use of aluminum-based coagulants is not restricted by the availability of their prime components. The natural bauxite resources are abundant and the production of sulphuric acid is common. Aluminum salts are produced from the dissolution of purified (or non-purified) aluminum tri-hydrate with sulphuric acid followed by a filtration. The cost of these coagulants generally varies with the volume produced and the distance between the production site and the water treatment plant. A health-based guideline for the presence of aluminum in drinking water has not been established (FPSDW 2001), however, water treatment plants using aluminum-based coagulants should optimize their operations to reduce residual aluminum levels in treated water as a precautionary measure. Operational guidelines of less than 100 µg/L of total aluminum for conventional treatment plants and less than 200 µg/L of total aluminum for other types of treatment systems are recommended (FPSDW 2001).

Alum is the most widely used coagulant chemical (AWWA and ASCE 1990). The U.S. EPA (1999) requires drinking water utilities to conduct jar tests using alum to establish their total organic carbon removal by enhanced coagulation. Enhanced coagulants are those that maximize pathogen removals, minimize residual aluminum, and produce low turbidities and particle counts (Edzwald and Tobiason 1999). Alum coagulation is the most popular reference in water treatment.

The complex forms of aluminum coagulant (PAS, PASS, PAC, etc.) usually cost twice as much as alum because they are derived from these salts (Tardat-Henry 1989). In order to reduce cost and to constantly produce good quality drinking water, producers often use alum in cases when raw water is easily treatable and they use complex forms, like PASS, when raw water is difficult to treat (A. Chartré, Ville de Longueuil, Quebec, Canada, pers. comm.; C. Sauvageau, Ville de L'Assomption, Quebec, Canada, pers. comm.). Complex forms are most used in Canadian winters when the raw water is cold and the chemical reactions are slower (Jolicoeur and Haase 1989; Tardat-Henry 1989; Edzwald 1993). PASS (which contains silicate, a mineral agent of polymerization) is preferred to alum in cold conditions because it instantly forms hydroxide aluminum flocs that adsorb contaminants on their surfaces (Exall and vanLoon 2000). Silicate allows PASS to reach a higher molecular weight than all other coagulants, including alum, polyaluminum chloride and ferric salts (Eaglebrook 2002). The optimized use of PASS, PAC and other complex forms normally produce lower soluble alumina residuals in the clarified water than alum does (Simpson et al. 1988; Eaglebrook 2002). The other complex forms, PAS, poly-aluminum chloride and pre-hydrolyzed alum, are also more effective than alum in cold-water conditions and their selection (between each other) is dependent on the raw water characteristics (pH, alkalinity, organic content, inorganic impurities) and the clarification process being used. Their use could also decrease or eliminate the need for polymer (flocculants). Bench-scale and pilot tests are required to select the best coagulant to use in any condition (AWWA and ASCE 1990).

Iron-Based Coagulants

The production of iron-based coagulants often depends on the availability of iron powders. Iron residues may be used as inexpensive sources. Liquid residues from metallurgical industries, containing ferrous iron in acid solution, may also be used to make iron salt solutions. Both of these iron sources are subject to contain more impurities than the use of purified iron powders. Iron salts are produced from the reaction of iron powders with acid and/or an oxidant. The complex iron-based coagulants are made using basic iron salts; therefore their prices are higher than those of iron salts.

The two most popular iron salts used to treat drinking water are ferric chloride and ferric sulphate. According to the AWWA and ASCE (1990), in some applications, ferric chloride may be more effective than alum, while ferric sulphate is as effective in some waters and more economical. A case study (Douglas et al. 1998) illustrated that the use of ferric chloride, at a lower pH, was more efficient than alum for organic removal using enhanced coagulation with comparable costs (I.P. Douglas, City of Ottawa, Ontario, Canada, pers. comm.). The residual aluminum concentration, when using iron-based coagulants in the treated water, was 0.024 and 0.097 mg/L for alum. Both concentrations are below the operational target of 0.100 mg/L (FPSDW 2001). However, using ferric chloride as a coagulant contributes to trace amounts of iron in drinking water. During a pilot plant experimentation, the iron concentration in the filtrated water (filtration removes most of the residual iron flocs) was 0.046 mg/L (Douglas et al. 1998), which is below the aesthetic objective of 0.300 mg/L for drinking water (FPSDW 2001). Nevertheless, the use of ferric chloride for full-scale drinking water production in Toronto provoked red water complaints (P. Newland, City of Toronto, Ontario, Canada, pers. comm.). Another trace contaminant introduced by ferric chloride is manganese. Concentrations of 0.046 mg/L were found when water was treated with this coagulant, a slightly lower value when compared to the drinking water objective of 0.050 mg/L (FPSDW 2001).

Ferric chloride is a corrosive compound and attacks metals rapidly. Ferric chloride can be stored in either fibreglass-reinforced polyester or rubber-lined steel tanks (Eaglebrook 2002), since aluminum, brass and stainless steel are readily attacked by this compound and should never be used in ferric chloride dosage equipment. Studies demonstrated that the use of iron-based coagulants corroded steel infrastructures (Shi et al. In press), and no significant differences of stainless steel corrosion occurred when the treatment infrastructures were exposed to alum or to ferric chloride coagulants.

Using ferric sulphate as a coagulant in drinking water treatment may exhibit higher operational costs than using alum, however it offers a higher satisfaction to the consumer. A drinking water producer in Saskatoon, who had changed from alum to ferric sulphate, was very satisfied even if his coagulant operating costs increased (Eaglebrook, pers. comm.).

Many metal impurities may be present in ferric salts due to their production process, as compared to alum, which is made from purified aluminum tri-hydrate. Regardless, iron coagulants used for drinking water treatment meet the National Sanitation Foundation (NSF) Standard 60 potable water standards (NSF 2002). Table 1 shows the single product allowable concentrations of metals in NSF-approved products for drinking water purification (NSF 2002).

The combination of ferrous sulphate and lime form an effective coagulant for the clarification of turbid waters (AWWA and ASCE 1990), which favour the application of this combination in wastewater treatment.

Although complex forms of iron coagulant can easily be produced, they are not frequently used in water treatment (Eaglebrook 2002; Wang 1987). The use of poly ferric chloride or poly ferric sulphate in drinking water or wastewater treatment has not been cited in literature. During bench-scale tests for the removal of algae in synthetic solutions, poly ferric sulphate was found to perform better than either alum, PAC or ferric sulphate (Jiang et al. 1993). The use of hydroxylated ferric sulphate is more advantageous for water and wastewater treatment, especially in low alkalinity environments. It is widely used in the mining and pulp and paper industries for a variety of different applications (Eaglebrook 2002).

Other Alternative Coagulants

The other coagulants found in the literature can be classified into two main groups: inorganic and organic coagulants. Lanthanide salts and calcium nitrate coupled with magnetite are the principal inorganic coagulants tested in the literature, while polymers, chitosan and *Moringa oleifera* are the major organic coagulants.

Inorganic coagulants. Lanthanides, also called rare-earth elements, are a group of 15 chemically similar elements with atomic numbers 57 through 71, inclusive. Yttrium (atomic number 39) is also included in the rare-earth elements because of its similar chemical characteristics (Hedrick 1985). The earth's crust is rich in lanthanides because their concentration is estimated

TABLE 1. Single product allowable concentrations of metals in NSF-approved products (NSF 2002) in drinking water treatment

Metal	*Concentration (mg/L)*
As	0.0025
Ba	0.2
Be	0.0004
Cd	0.0005
Cr (total)	0.01
Cu	0.13
Hg	0.0002
Pb (at tap)	0.0015
Se	0.005
Sb	0.0006

at 150 g/tonne (Sneed et al. 1985). Cerium, neodymium and lanthanum are the most abundant lanthanides, and together, their quantity is more significant than nickel or copper. Lanthanum nitrate and lanthanum chloride have been studied as coagulants for wastewater treatment (Retch et al. 1970; Taouzi 1995), demonstrating a great potential to remove phosphate from wastewater. No present application in drinking water treatment has been cited using lanthanum chloride or derived lanthanum compounds. A commercial product, named Lanthanum Concentrate (containing lanthanide oxides), exists on the market (B.T. Kilbourn, Molycorp Inc., pers. comm.), however its price (about \$0.80/mole) is much higher than the cost of alum (about \$0.12/mole) or ferric chloride (about \$0.10/mole).

Nitrate calcium coupled with magnetite has been studied for electromagnetic wastewater clarification. The flocs are ballasted by magnetite and the electromagnetic field improves the settling process. However, this promising process needs further research and new infrastructures, therefore its costs cannot be compared with simple coagulant changes.

Organic coagulants. Organic polymers are frequently used as flocculation aids and conditioning agents for sludge dehydration. They may be anionic, cationic, nonionic or mixed. Their performances depend on the function of the product used and the characteristics of the raw water. Cationic polymers may be used alone as the primary coagulant, or in conjunction with aluminum or iron coagulants (AWWA and ASCE 1990). Natural organic polymers have been used as coagulants for more than 2000 years in India, Africa and China. They may be manufactured from plants seeds, leaves and roots (Kawamura 1991). Tannin biopolymer can also be used for water treatments, but only as a coagulation aid (Özacar and Sengil 2003). These natural organic polymers are interesting because comparative to the use of synthetic organic polymers containing acrylamid monomers, no human health danger from their use has been identified. Residual acrylamid monomers occur in polyacrylamid coagulants used in the treatment of drinking water. In general, the maximum authorized dose of synthetic polymer is 1 mg/L (WHO 1993), which eliminates their use as prime coagulant. This applies to the anionic and non-ionic polyacrylamids, but residual levels from cationic polyacrylamids may be higher.

Chitosan (a residue of crustacean transformation) and *Moringa oleifera* (a tropical plant) are very efficient natural organic coagulants in water treatment (Kawamura 1991; Johnson and Gallanger 1984; Murcott and Harleman 1991, 1992, 1993; Ndabigengesere et al. 1995; McConnachie 1993; Tagherouit et al. 2003). These organic coagulants are biodegradable, non-toxic, non-corrosive and easy to use. *Moringa* may be useful for the production of drinking water in developing countries where other coagulants are expensive and the operators are not well trained (Jahn 1988).

Practical applications of these organic polymers (natural and synthetic) as prime coagulants are rare because of their high operational costs. Nevertheless, the use of organic coagulants produces a smaller volume of clarification sludge than the use of metallic coagulants (Ndabigengesere et al. 1995). Sludge produced from clarification processes using natural organic coagulants does not contain added metals or toxic compounds.

Discussion

The substitution of aluminum-based coagulants for water treatment plants implies coagulant/flocculant changing, process reoptimization and installation retrofitting, affecting most water treatment plants in Canada, because aluminum-based coagulants are the most used for clarification. Changing the process may also be required in some water treatment plants where the raw water is difficult to treat in specific environments. The effects of these modifications may be classified into four categories: technical, economical, social and environmental impacts.

Technical Impacts

The alternative coagulants presently available for water treatment are iron salts; however, their efficiency for the treatment of different raw waters in cold conditions is not well documented. All other alternative coagulants need further investigation. The literature lacks studies about complex iron-based coagulants (hydroxylated ferric chloride, poly ferric chloride and poly ferric sulphate) and lanthanides salts for drinking water treatment. The synthetic organic coagulants could not be used as prime coagulants due to their acrylamid monomer content.

The use of more corrosive products (ferric chloride) may necessitate modifying the dosage equipments (storage tanks, pumps, piping, valves and accessories). Process operations will be affected by the application of these modifications because of temporary treatment shutdown.

Implementing alternative coagulants would require a clarification reoptimization. This implies that bench-scale and pilot-scale tests with different coagulants and flocculants are required using trained operators. Preliminary tests must be carried out on a year-round basis in order to produce a similar drinking water quality to the one actually produced in cold waters, in spring and in autumn (where raw water quality changes very rapidly). Furthermore, the changes in coagulant (dose and/or type) affect the overall water quality, which impacts the rate of lead and copper corrosion (AWWARF 1985). This impact, which leads to the addition of corrosion inhibitors in the water produced, must also be taken into consideration.

In some treatment plants, where the contact time between the treated water and the coagulant is short and the use of polymerized aluminum-based coagulants is necessary, some infrastructure modifications are required in order to increase this contact time when using iron salts. Furthermore, clarification replacement by another process may be required if iron salts are not effective. Only membranes have been identified as the best technology for clarification replacement.

Economical Impacts

Analysis of the 1991 to 1999 Municipal Water Pricing Survey (for municipalities with populations greater than 1000) indicates that the average domestic water user pays C$1.00/m^3 in 1999 (MPWGSC 2001) for drinking water consumption and wastewater treatment. This value has increased substantially in recent years, and includes a waste treatment component of about 39.4% (MPWGSC 2001). Considering that Canadian residential drinking water use rose to 343 litres per person per day by 1999 and that 23.1 million Canadians are served by the concerned municipalities (MPWGSC 2001), the total cost of drinking water in municipalities is approximately 1.8 billion dollars a year.

Canada has about 4000 municipal drinking water treatment facilities (Federation of Canadian Municipalities 2001). Groundwater is the source of water supply for 25 to 30% of the population of Canada (Canadian Geosciences Council 1993). The remaining 70 to 75% is provided by surface waters that are usually treated by clarification (U.S. EPA 1998; MENVQ 2002) and normally use aluminum-based coagulants (Eaglebrook, pers. comm.). Municipalities serve 23.1 million Canadians, therefore 16 to 17 million Canadians, and 2900 municipalities (0.725 x 4000), would be affected by a substitution. These values may vary depending if surface waters require clarification and if coagulation is required to treat some contaminated groundwater. No statistical data concerning coagulation use was cited in the literature.

The substitution of aluminum-based coagulants by alternative coagulants will certainly increase the short-term cost of the produced drinking water by Canadian municipalities. The cost of iron-based coagulants depends on its availability and on the cost of transportation. Municipalities in remote locations such as Saskatoon would have to pay up to 150% more for coagulants (Eaglebrook, pers. comm.). This may decrease in the future due to the demand increase of iron-based coagulants and the construction of new facilities fabricating iron-based coagulants (Eaglebrook, pers. comm.). In cities such as Ottawa, the cost of iron-based coagulants used is comparable to the cost of aluminum-based coagulants (I.P. Douglas, City of Ottawa, Ontario, Canada, pers. comm.; Douglas et al. 1998). The cost of iron-based coagulants may increase due to the modification made to the actual fabrication process, in order to reduce manganese contamination of the treated drinking water as observed by Douglas et al. (1998). The replacement of flocculants, due to coagulant change, is difficult to quantify because it is dependent on the quality of the raw water treated. The cost of coagulants accounts for about 5% of the price of the drinking water produced (N. Arcouette, Ville de Laval, Quebec, Canada, pers. comm.). Therefore, the cost of coagulants for Canadians using drinking water produced by clarification (70–75% of the population of Canada) is approximately 65 million dollars a year (5% x 72.5% x 1.8 billion dollars). Future use of alternative metal- and organic-based coagulants would decrease their cost.

Process reoptimization (process re-design) and the research of new alternative coagulants will necessitate investments from the municipalities, provincial and federal governments. Research and development activities will have to be rapidly organized and implemented in all concerned municipalities in order to collect more information about the efficiency of alternative coagulants in all water conditions. Experiments of new alternative coagulants will need to be carried out in municipalities where iron salts will not be efficient. Research and development activities are necessary in order to evaluate the health impacts of all alternative coagulants used in drinking water production (metal-based and natural organic coagulants). If ferric chloride is utilized, dosage equipments may have to be replaced in order to resist this corrosive product. A drinking water producer estimated this replacement cost at $300,000 for each treatment plant (N. Arcouette, Ville de Laval, Quebec, Canada, pers. comm.). If only half of the 2900 drinking water treatment plants using aluminum-based coagulant in Canada would have to make such modifications, it would cost approximately 435 million dollars. In some municipalities that would need to change their clarification process to a membrane process due to difficulties in treating their source waters, the substitution of aluminum-based coagulants may double the production cost of their drinking water (Najm and Trussel 1999).

Social Impacts

The major social impacts of substituting aluminum-based coagulants are sanitary impacts on the population, population perception about drinking water quality and impacts on the process operators.

The substitution of aluminum-based coagulants will change the drinking water quality. The substitution of alum by iron-based coagulants would certainly decrease aluminum residues in treated water (Douglas et al. 1998). This decrease would be lower when complex aluminum-based coagulants are used, since they do not produce as much aluminum residues as alum (Simpson et al. 1988; Eaglebrook 2002). Using iron-based coagulants may alter water colour due to the presence of iron residues (P. Newland, City of Toronto, Ontario, Canada, pers.

comm.). This red water produced may affect public perception about the drinking water quality.

All iron-based coagulants recommended for drinking water treatment are meeting international standards at normal dosages (Table 1; NSF 2002). However, the presence of manganese in Ottawa (Douglas et al. 1998) raises some questions about the use of metallurgical residues to fabricate iron-based coagulants. The use of purified iron powders would be recommended and NSF criteria concerning all metals must be established. Actually, NSF standards do not consider aesthetic parameters, like manganese presence in drinking water (NSF 2002). Coagulation change (dose and/or type) affects the overall water quality, which also affects the rate of lead and copper corrosion (AWWARF 1985). The effects of the release of these metals on the population's health and perception (metallic taste of copper) must also be considered.

Modifications of the coagulation conditions, due to coagulant replacement, may impair clarification efficiency and favour pathogen breakout in drinking water, like the protozoa (*Giardia* and *Cryptosporidium*) breakout observed in Sidney, Australia, (CRCWQT 1998). At all times, water treatment modifications must not affect water quality. Controlling the potential consequences caused by microbial contamination is of extreme importance and must never be compromised (WHO 1998). Therefore, process reoptimization must be performed before any coagulant replacement with experimental work being carried out at both the bench scale and pilot testing levels on a yearly basis in order to identify the appropriate dosages and to ensure safe drinking water in all raw water conditions (AWWA and ASCE 1990). Operators of drinking water plants will need to be cautious about this fact and they need to be trained in the use of more corrosive products like ferric chloride.

Environmental Impacts

The substitution of aluminum-based coagulants may have environmental impacts depending on the sludge disposal mode used in the different drinking water plants. Most sludge from clarification processes is released at periodic intervals in the sewers in order to facilitate the wastewater treatments. Therefore, coagulant changes may not affect significantly the efficiency of a chemical wastewater treatment. Agricultural valorization of sludge containing coloured iron oxides (red oxides produced from the use of iron-based coagulants) may be difficult. On the other hand, the use of natural organic coagulants would facilitate sludge disposal and valorization for agricultural activities. They will also reduce the volume of the sludge produced.

From the perspective of sustainable development of our industrial society, the impacts of chemical use for drinking water treatment have to be analyzed and evaluated. The long-term resource availability will limit the use of all metals, and in this case, the use of alternative metal-based coagulants (iron and lanthanides) is not an appropriate long-term solution. The use of renewable natural organic coagulants is preferable, but many aspects regarding their industrial use have to be explored by research and development projects. Alternative processes, like membranes, may actually require more implementation resources (capital cost) and energy (pressure drive), but their generalization and further research and development will certainly reduce these impacts. In fact, considering raw water as a resource, our actual residential drinking water consumption in Canada, 343 litres per person per day (MPWGSC 2001), is well above the minimum standards in water supply and sanitation of 15 litres a day (OXFAM 2000). Energy and resource optimization requires that we use only the needed resources to produce a high-quality drinking water and that we use minimal treatments to produce service water (for fire fighting, toilet flushing, car washing, grass watering, etc.). This may be achieved by using point-of-use treatments (treatments at the consumer tap) or by the implementation of two distribution systems. These alternatives would limit the use of non-renewable chemicals in drinking water production, however further research and development and a general shift in our perception of water as a vital resource is required.

Conclusions

Substituting aluminum-based coagulants requires that all the possible technical, economical, social and environmental impacts be considered. Each situation must be analyzed and evaluated. The actual alternative iron-based coagulants may not be appropriate for the treatment of all raw waters in all conditions. Coagulation problems may occur for many raw waters in different conditions. Moreover, the use of iron salts causes metal contamination of the drinking water produced.

Further research and development activities are required in order to limit the technical, economical, social and environmental impacts identified below of substituting aluminum-based coagulants:

- Purified iron-based coagulants (salts and complex forms) need to be developed and many industrial production sites must be constructed across Canada.
- Other alternative coagulants, like lanthanide salts and natural organic coagulants, need to be evaluated at the industrial scale and commercialized in order to guarantee a large range of coagulants available for the treatment of all raw waters in all conditions.
- Alternative processes, like membranes, will have to be implemented in municipalities where alternative coagulants will not be efficient.
- Sustainable development concepts must be applied in the drinking water production and distribution.

The use of non-renewable chemicals and energy must be minimized when producing service water.

Furthermore, all alternative coagulants will need to be carefully studied and implemented, especially in small municipalities where staff formation will be necessary. In all cases, treatment modifications must not affect water quality and the potential consequences caused by microbial contamination are such that its control must always be of paramount importance and must never be compromised (WHO 1998). The implementation of enhanced coagulations, which maximize pathogen removals, produces low turbidities and minimizes residual aluminum (Edzwald and Tobiason 1999), in Canada's water treatment plants using alum-based coagulants would be a low-cost solution in a short-term perspective.

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