ALTERNATIVE TREATMENT TECHNOLOGIES FOR THE CONTROL OF CORROSION, COLOUR, IRON AND MANGANESE IN NEWFOUNDLAND COMMUNITIES DRINKING WATER SUPPLIES.

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ABSTRACT

This work summarizes the results of process studies carried out in eight Newfoundland communities to improve drinking water supplies. Treatment technologies were evaluated to upgrade existing chlorination systems, reduce the impact of the aggressive water supplies, and to control colour and dissolved minerals. Health related concerns associated with high levels of dissolved aluminum, asbestos and trihalomethanes were addressed. General design information of installed systems is presented, supplemented by specific examples.

INTRODUCTION

Pollutech Limited has been involved with DELCAN, formerly DeLeuw Cather Canada, since the early 1980's in the evaluation of water supplies and treatment technologies to provide good quality potable water to several small communities in Newfoundland. These projects have been unique in that several small communities have all had trouble with severely corrosive water that is highly coloured due to the presence of dissolved iron and/or manganese. Raw water analysis was conducted for eight communities; in some communities several alternative raw water locations were studied. Raw water quality was linked to the types of problems being experienced in these communities.

The actual communities that were studied in the project are Whitbourne, Placentia, Jerseyside, Harbour Main, Rose Blanche, Portugal Cove, Dunville, and Burgeo.

This project was not undertaken as an overall review of water quality and treatment technologies available for the Province of Newfoundland, but rather as a series of individual studies carried out by the communities themselves with varying degrees of provincial funding in support of the evaluations. Each project was unique and the question or study approach was not always identical. Technical information achieved from each community's project was extracted and tied together to present some ideas as to what is being found in the different communities and the variability with respect to control technologies that have been determined.

THE SCOPE OF THE PROBLEM

In reviewing each of the projects, we have assembled a list of the major concerns that came out of the projects that were either very serious in nature to one particular location, (although it may not have been prevalent at each location), or problems that were encountered in the majority of the communities evaluated. The typical problems that we have found are as follows:

- high water leakage from badly corroded water distribution systems,
- coloured water from organically bound iron, and in some instances manganese,
- poor retention of chlorine residuals from high chlorine demand of the raw water,
- high operation and maintenance costs due to leakage, and
- high capital costs due to complex, treatment required.

Due to the highly corrosive nature of the water in these communities, there has been severe deterioration of water mains and house connections. This has resulted in a great deal of leakage in a majority of these communities. High usage rates are also sometimes due to a common practice, especially in older style homes, of running all taps continuously during winter weather conditions. For example, in Rose Blanche the water usage triples from this practice. We have assembled some generalized data from the communities as shown in Table I which shows per capita water consumption in the range of 450 to 900 liters per capita per day. Initially the total usage for the Town of Placentia was approximately 5500 liters per minute or 3570 liters per capita per day. Upgrading of the distribution system has now reduced flow to the range listed in Table I (i.e. 1030 liters per capita per day). Actual numbers available for the communities in which consideration to all sources of leakage has been given, shows that per capita consumption is more in line with 135 to 230 liters per capita per day. It is obvious, therefore, that any water treatment facilities that are to be installed and operated for these communities must be sized well in excess of the actual water consumption rates, unless significant steps are taken toward rehabilitation of the water distribution systems to prevent the excessive leakage.

TABLE 1: Typical Water Usage

Community	Population	Water (m^3/day)	Consumption (litre/capita/day)
Placentia	2,200	2,270	1,030
Burgeo	2,800	4,900	1,750
Dunville	2,000	1,160	580
Rose Blanche	960	230	240

The leakage of water from the system is itself dependent to a great extent on the water quality for each of the communities. If one parameter had to be selected that was prevalent in each community, it would have to be the aggressiveness of the raw water. Routine raw water quality data, collected for the communities during these individual projects have been summarized and are shown in the attached Table 2. The pH levels of the raw water range from a low of 4.2 to a high of 6.5. With corresponding low levels of total alkalinity and calcium hardness, calculated values for the Ryznar indices are very high.

TABLE 2: Typical Raw Water Quality

Community	pH	Colour	Fe (mg/L)	Mn (mg/L)	R.I.
Placentia	5.0	52	0.36	0.02	19.7
Whitbourne	4.2	-	0.39	-	18.9
Portugal Cove	5.2	40	0.14	-	17.9
Harbour Main	6.5	21	0.01	0.01	13.1
Rose Blanche	5.7	46	-	0.02	15.3
Standards	6.5 - 8.5	15	0.3	0.05	6

Ryznar Index values greater than 6 are progressively corrosive. This suggests that this water would be extremely aggressive to all forms of distribution system materials in use in the province of Newfoundland.

In two particular cases, detailed analytical work has been carried out with respect to concerns regarding the aggressiveness of the water. In the first instance, as found in the Town of Whitbourne, the water was so aggressive that water mains and laterals to the houses were crumbling and, as a result, excessively high leakage was occurring. Residents of this community also complained of green discoloration from the water supply system and a blackening of starch products (i.e., potatoes) boiled in water. A review of the particular water quality in a few of these residences, as outlined in Table 3, shows the result of the staining and the discoloration to be the result of elevated copper levels in the water at the tap. Analytical test data clearly showed that the elevated copper levels were the direct result of the corrosion of the copper distribution system and not from naturally occurring background material. Levels as low as 0.01 mg/L found in the raw water reached peak levels of 2.40 mg/L in the hot water supply system. Aesthetically acceptable levels for concentrations of copper are reported at 1.0 mg/L (National Health & Welfare, 1937). The occurrence of black staining of food as a result of cooking in boiling water can be associated with the reaction of the water containing the copper with aluminum pots at the elevated temperatures.

TABLE 3: Corrosion of Water System (Town of Whitbourne)

Location	pH	Fe (mg/L)	Cu (mg/L)
Water Intake	6.6	0.21	0.01
Hydrant	5.9	2.50	0.03
Cold Water	4.2	0.39	1.15
Hot Water	4.7	0.30	2.40

A serious concern with respect to water main corrosion was also found in the Town of Dunville where the water had a pH of 5.8 and a Ryznar Index of 15.4. In this particular installation, however, the concerns were with respect to asbestos fibers present in the water from the degradation of the asbestos cement water mains. Preliminary testing showed asbestos fibre concentrations as high as 26,000 ng/1 as compared to background levels of 0.7 ng/1. Analytical data for the Dunville samples is given in Table 4.

TABLE 4: Analysis for Asbestos Fibers (Town of Dunville)

Asbestos Count	**Amphibole Wyses Pond**	**Amphibole Town Hall**	**Chrysotile Wyses Pond**	**Chrysotile Town Hall**
Mean (10^6 fibers/litre)	0.27	8.9	0.26	600
Mass (ng/L)	-	1600	0.7	26,000
Number of Fibers	0	17	1	116

The analytical results reveal that there was in excess of a six hundred fold elevation of the asbestos fibre level in the distribution system (Town Hall) water sample as compared to the sample from the source (Wyses Pond). The identification of the amphibole fibre crocidolite provides very strong evidence that asbestos fibers are being released from the walls of the asbestos cement water piping system.

In 1987 the presence of asbestos fibre was confirmed when DELCAN personnel, assisted by the Town work force and a private local water main cleaning contractor, polypigged 12,800 meters of asbestos cement pipe. In one particular section, just downstream of the intake, the pig lodged in the water main. The water main was excavated and the top was cut out of the pipe. A 4.5 meter section was blocked solidly with asbestos fibre.

In addition to the highly aggressive nature of the water, the majority of the water supplies that have been tested to date show elevated levels of apparent colour ranging from 20 platinum-cobalt units (PCU) to 50 PCU, with peak colour readings having been noted at the 100 PCU level or greater.

Although a detailed investigation has not been made as to the true origin of the colour, the numerous test results would suggest that the elevated colour is a result of high levels of iron, and sometimes manganese, found in the raw water supplies. Test work at the various communities has shown that the dissolved iron and manganese are present both in the free and the organically bound form and the ratio of free to organically bound iron varies from community to community.

TREATABILITY OPTIONS

The ongoing investigation of water treatment concerns and available options to improve the water quality for these communities in the Province of Newfoundland has resulted in the development of several alternative scenarios for water treatment. In evaluating the treatment technologies for either corrosion control, colour removal, or dissolved metals removal there were several concerns that had to be given careful consideration before selection of an appropriate treatment technology. Typically these included the following:

1. There was excessive distribution system leakage and therefore high volume water

usages relative to the size of the community.

2. The major water supplies were subjected to extreme variations from seasonal trends in water quality often stemming from the leaching of humic material and metals from the natural environment.
3. The degree of bound versus free iron fluctuated with the seasonal input of humic material resulting in the need for complex treatment technology, but only at select periods during the year.
4. The treatment options available were generally high cost capital equipment projects if minimal operating costs were required, or for the low cost capital projects, high operating costs due to chemical addition and associated sludge handling.
5. Very little water treatment was currently being carried out and therefore construction of a new facility was required. This dictated the need for routine operation of a facility and the associated personnel training and cost.

Corrosion Control

A common problem to all the communities was the severely aggressive water and its impact on the water distribution system. Therefore, it was essential for each of the communities to implement a procedure for corrosion control through the stabilization of the water supply. In the simplest sense this requires the addition of an alkali to increase the pH to neutral conditions. This can be accomplished using a hydroxide-base material such as calcium hydroxide ($Ca(OH)_2$) Or through the addition of a carbonate such as sodium bicarbonate ($NaHCO_3$) or sodium carbonate (Na_2C0_3). The hydroxide bases work very quickly to elevate the pH, however they do not provide for stability of the water supply system. The best control technology calls for the addition of both a calcium based hydroxide and a carbonate so as to provide for the necessary chemical reactions that result in stabilization of the water supply and also the tendency to precipitate a calcium carbonate film on the pipe linings. The least expensive chemicals which can react quickly to elevate the pH are also those that require the more sophisticated pH control systems to maintain the final required pH. Alternately, the weaker alkali, such as sodium bicarbonate, can be implemented with a less sophisticated metering pump system or pH control system, but the associated chemical costs are high. For the preliminary investigations the standard chemical treatment for corrosion control was a system proposed to feed a mixture of 80 percent calcium hydroxide and 20 percent sodium carbonate. This provides for stability of the pH control' system while at the same time providing a source of carbonate alkalinity and calcium for the thin film deposition of calcium carbonate.

Colour Removal

A number of the communities did require treatment for colour removal, which in some cases included the removal of excessive iron. Several different technologies were evaluated and a significant difference in the effectiveness of the treatment technologies was observed at different communities. The general procedure in the tests was to carry out lab scale treatability tests to screen a number of conventional treatment technologies. On the basis of preliminary screening results, detailed bench scale tests were then completed to determine such items as reactor conditions, chemical costs, and sludge production. A typical example of the screening procedure is shown for the Town of Placentia (Southeast River source) in Table 5. Treatment was proposed for the reduction of the high levels of apparent colour, often exceeding 85 PCU.

TABLE 5: Placentia Water Treatability (Colour Units - PCU)

Treatment	Settled Water (PCU)	Treated Water (PCU)
Aeration	70	70
Aeration + Lime	40	10
Lime Only	50	20
Chlorine + $FeCl_3$	40	5
Chlorine Only	35	30
Activated Carbon	110	60
Lime + Permanganate	35	10
Ozonation	70	70
Aeration + Alum	70	70

In the case of Placentia the only way the colour could be removed was through the addition of high levels of lime, or combinations of lime and sodium carbonate, in conjunction with aeration. There are, however, considerable drawbacks to this process with respect to sludge production, sludge disposal costs, and significant chemical costs. The impact of the aeration lime process on the colour removal is dramatic, however, as depicted in Table 6 the impact of the various chemical constituents on the costs of the treatment can be significant.

TABLE 6: Typical Costs (1980 $) for Corrosion Control

Treatment (lime/soda)	Lime (kg/1000 m^3)	Soda (kg/1000 m^3)	Lime ($/1000 m^3)	Soda ($/1000 m^3)	Total Cost ($/1000 m^3)
100/0	4.25	0	0.31	0	0.31
80/20	4.40	1.10	0.33	0.36	0.69
50/50	3.13	3.13	0.23	1.02	1.25
0/100	0	13.5	0	4.39	4.39

As a result of this analysis, it was recommended to the Town of Placentia to abandon the Southeast River as a source of water and to service the whole town from Larkin's Pond located in Jerseyside.

As noted in the data provided in Table 5, many of the common treatment technologies such as oxidation with chlorine, ozone or permanganate did not provide the expected levels of colour removal where the colour is associated with the high concentrations of iron. Preliminary testing suggested that the presence of the organically bound iron resulted in the need for excessively high doses of the oxidant to break the organic molecules prior to the metal oxidation. With the lime treatment process, however, a dense yellow sludge was produced at elevated pH with a subsequent removal of the iron.

The aerated lime process in its simplest form would require a typical lime treatment system. Package plants can be purchased which provide this type of treatment including aeration, clarification and settling. In addition to this, pH adjustment is required prior to chlorination and distribution into the system. In a large municipality the cost could warrant the construction of a re-carbonation plant, however this would be difficult to justify in these small communities which have a population of only a few thousand people. Therefore, in its simplest form the basic water treatment procedure would call for high levels of lime addition and a corresponding need for neutralization prior to discharge.

In some communities, where less of the iron was organically bound, Standard procedures for chemical oxidation appeared to work favorably. In these instances the control technology then became a matter of determining the optimum treatment using either ozone, chlorine or potassium permanganate. There are advantages and disadvantages to each of these chemical oxidants.

With each of the chemical oxidation systems that include the introduction of alkali to control the pH, it can be expected that some particulate matter will form either from the oxidation of the organic material or through a chemical reaction with the alkali. As such, it is necessary to provide for filtration (or sedimentation plus filtration) in any form of water treatment plant. One can assume that for the chlorination and the ozonation system a sand or dual media filter would be utilized whereas with the potassium permanganate system a manganese-greensand filter would be used.

For facilities that require high levels of ozone or chlorine to oxidize the organic material, some procedures would have to be put into place for de-chlorination or de-ozonation of the water supply prior to distribution. Ozonation is less difficult to deal with because the residual ozone can be easily destroyed, whereas the process of chlorination/de-chlorination requires activated carbon absorption or the addition of sulphur dioxide.

PILOT SCALE TESTING

Pilot scale evaluations were carried out for the Town of Dunville. A pilot scale ozonation system was set up on site to evaluate single and double stage ozonation in combination with filtration for treatment of colour, bound iron and odour.

The Dunville pilot plant consisted of two 10 cm diameter, 6 meter ozone columns and a 0.28 m,£ sand filter. Testing was carried out with and without pH adjustment prior to ozonation, at various levels of ozone, and with one or two stage ozonation.

The pilot test evaluated the following conditions:

1. single stage ozonation for direct discharge,
2. single stage ozonation followed by filtration prior to discharge,
3. dual stage ozonation incorporating filtration between two stages, AND
4. ozonation incorporating the proposed lime carbonate pH adjustment system

Results of the pilot plant ozonation studies indicated the following:

1. With a single stage system without filtration and at an ozone dose of approximately 6 mg/1 the raw colour could be reduced from 30 PCU to 7 PCU.
2. Sand filtration as a follow-up to single stage ozonation resulted in an increase in turbidity and colour, suggesting contamination in the filter system.
3. Two-stage ozonation in conjunction with filtration resulted in a colour change from 24 PCU in the raw water to 6 PCU in the finished water at a total 4 mg/L of ozone (applied as 2 + 2).
4. At an applied dose of 12 mg/L ozone the colour could be reduced to 5 PCU in a one column system without filtration.
5. Variations in the ozone dose suggested the optimum ozone application in a one or two stage system is 6 mg/L.
6. pH adjustment by a lime-carbonate mixture prior to ozonation caused a slightly negative change in the colour removal.

Evaluation of the test data suggested that two major alternatives should be considered for the Dunville process.
Historical records suggest that the turbidity increases during periods of heavy runoff. If the turbidity was to increase significantly, then it could interfere with the ozonation reaction. The increased ozone demand would mean less available ozone for treating the colour and odour, therefore the level of treatment the community would be expecting, or be accustomed to, would be reduced. Providing for optional filtration ahead of the system means that during periods. of high influent turbidity the filter could, be put in operation, thereby allowing the ozonation process to proceed as expected.

A filtration system after ozonation would be essential under two separate, but related conditions where either the pH adjustment to near neutral is carried out prior to ozonation for corrosion control, or where pH adjustment to basic conditions is practiced in conjunction with elevated ozone levels for the oxidation of iron compounds. In either case, the result is the chemical formation of oxides, hydroxides and carbonates that would appear as a white turbidity. This insoluble matter would have to be removed by filtration prior to distribution.

The alternative to providing post filtration is to add pH control chemicals after ozonation only, and to limit the ozone dose to below that required for oxidation of the soluble iron. This would significantly reduce the chance of producing insoluble metal oxides, hydroxides and carbonates.

On the basis of the pilot plant ozonation studies a process schematic was developed for an installation in the Town of Dunville. This system would be designed as follows:

1. A single stage ozonation system capable of providing an ozone dose of approximately 6 mg/1.
2. Accommodation for either pre-filtration or post-filtration.
3. For the 1350 m3/day flow, allowance for initial ozone production capacity of 8.2 kg/day.
4. A minimum mean hydraulic retention time in the ozonation reactor of 5 minutes.
5. Provision for chlorine addition for residual disinfection as a follow-up to the ozonation procedure.

One of the alternatives that was considered to have merit was the use of one filter, which could be used before or after the ozonation system. Assuming that a pressure filter could be used, an operation could proceed in either one of two modes, with the option to switch back and forth.

A preliminary cost estimate was prepared for the Dunville ozonation system based on a water demand of 1360 m3/day. The cost of the treatment system was estimated at $635,000, with a further projected operation and maintenance cost of $27,000 per annum.

DISINFECTION REQUIREMENTS

For any of the water treatment plants consideration must be given to effluent disinfection and the supply of adequate disinfection capacity within the distribution system. As can be seen from the previous discussions the supply of chlorine or other disinfectants is greatly inflated due to the high level of leakage experienced in many of the water distribution systems.

Another major problem exists with the chlorine application as a disinfectant in these water supplies. With the high chlorine demand, resulting from the residual organic and dissolved metal in the raw water, there is a rapid loss of chlorine in the distribution system. These conditions have been further complicated by the development of a slime film on the inside of many of the water distribution pipes which further increases the chlorine demand. Studies of the chlorine demand as a function of water main length and temperature were carried out for the Town of Jerseyside. Larkin's Pond is the source of water for both Jerseyside and Placentia which has resulted in a very long distribution system. In this particular instance the chlorine dose supplied at the pumping station deteriorated rapidly within the distribution system. To achieve measurable chlorine residuals, chlorine had to be applied at such a high dose that it was objectionable to the users located in the preliminary sections of the distribution system.

A bench scale evaluation of the chlorine decay was carried out at three temperatures for the water supply, without inclusion of the decay brought about by the slime build-up in the water distribution system. The preliminary tests showed the following:

1. the rate of chlorine loss from the system will vary with the raw surface water temperature,
2. the initial rate of chlorine loss for all temperatures studied ranged between I mg/L/hour to 2 mg/L/hour, indicating an initial high dose of chlorine will be required to get past the initial high chlorine demand,
3. with detention times greater than 10 hours the chlorine decay is about 0.1 mg/L/hour suggesting residuals will be hard to maintain in long distribution systems, and
4. if a chlorine residual of 1 mg/1 was required after 24 hours in the system, an initial dose of 6.5 mg/1 would be required (at $2O^{o}C$), which would result in offensive levels of chlorine in the first sections of the distribution system

Several alternatives can be developed for dealing with this chlorination problem, such as the use of chloramines as an alternative disinfectant or the installation of booster stations for chlorination. The real answer to the problem, however, is in the treatment of the water prior to chlorination to reduce the chlorine demand. This has a two-fold impact in that it reduces the development of the scum layer within the distribution system and its associated chlorine demand and as well it reduces the general chlorine demand of the raw water. Without the installation of any up-front water treatment, we believe it would be extremely difficult to maintain a chlorine residual for any length of time within any of the water distribution systems.

INSTALLED SYSTEMS

Work carried out by the DELCAN/Pollutech team to date has resulted in several of the small communities undertaking to install corrosion control systems of one sort or another as a start to dealing with the water quality problems. The intent has been to deal with the corrosion problem in the water followed by repair or redevelopment of the water distribution system, prior to undertaking any major water treatment works. Without the corrosion control and reduction in high leakage rates within the systems any of the water treatment plant proposals would be excessively oversized resulting in equipment and chemical wastage.

Facilities that had been installed subsequent to the process studies detailed above have included the following:

Whitbourne

Soda Ash for corrosion control installed in the existing pump house.

Portugal Cove

Soda Ash treatment for corrosion control; chlorine for disinfection. This was installed as part of a new water system. A new building was constructed to house the treatment equipment and chemical storage plus screening and metering.

Burgeo

Lime and Soda Ash treatment for corrosion control. A new building was constructed adjacent to the chlorination building to house the treatment equipment and for chemical storage.

Harbour Main

Soda Ash treatment for corrosion control. This is a new water system.

Jerseyside

Soda Ash treatment for corrosion control and a new paced chlorination and retention chamber for disinfection was installed as part of a new pump house project. This system has been in service for 35 years.

Dunville

In the process of design and installation of an ozone treatment plant with filtration; pH adjustment equipment has been temporarily installed at the existing chlorination building until the new treatment building is in place in 1990. This is a complete new treatment facility for an existing system which has been in service for 20 years.

Rose Blanche

The town is in the process of installing Soda Ash for corrosion control and a chlorine booster station at the reservoir to overcome chlorine residual problems in the system (existing system).

SUMMARY

Although the problems experienced with water quality and water treatment in the communities studied to date have been varied, there have been several key components found in the different communities that are causing problems with water treatment and/or water supplies. In summary these are as follows:

- a extremely aggressive water supplies,
- deterioration of water distribution systems,
- corresponding high water consumption due to excessive leakage,
- wide fluctuations in raw water quality with seasonal runoff,
- appearance of dissolved metals in both the organically bound and free state within the same water supply, and
- complex (operational or construction basis) water treatment required to remove the aesthetic problems and associated dissolved metals

The rational approach towards the improvement of water quality and water supply within these communities would appear to be as follows:

- installation of chemical dosing systems to correct for severely aggressive water or alternatively, selection of ground water supplies or alternate surface water supplies that are not so aggressive in nature,
- repair of existing water distribution systems to cut down on the high degree of leakage in conjunction with the installation of corrosion control systems,
- cleaning of existing water distribution systems either with high pressure water or pigs to remove the build up of dissolved metals and slime on the interior of the water distribution system,
- screen alternate technologies and costs for water treatment once actual water consumption rates have been documented,
- pilot plant programs to document the suitable technologies, and
- design and installation of the water treatment facility.

To deal with these problems in Newfoundland, funding is required not only for the design and construction of the facilities, but more importantly, for the operation and maintenance of the systems.

Because of the wide variation found between the communities and within the seasons in any one community, it is essential that a water treatment process selected for one community is not automatically selected for a neighboring community. Treatment technologies must be adequately pre-screened so as to avoid total failure of the water treatment system.

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