FINAL REPORT
FOR

FIELD INVESTIGATION OF DOMESTIC HOT WATER TANKS AS SPACE HEATING APPLIANCES

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

FINAL REPORT
FOR

FIELD INVESTIGATION OF DOMESTIC HOT WATER TANKS AS SPACE HEATING APPLIANCES

Prepared by:

Rick Thrall
and
William J. Mayhew, P.Eng.

HOWELL MAYHEW ENGINEERING, INC.
15006 - 103 Avenue
Edmonton, Alberta
T5P 0N8

April 25, 1989

TABLE OF CONTENTS

	Page
Table of Contents	i
Executive Summary	ii
1.0 Introduction	1
2.0 Project Objectives	1
3.0 Description of work	
3.1 Regulatory Agency Interviews	2
3.2 Identification of Tanks	3
3.3 Cost Implications	5
4.0 Results and Discussions	
4.1 Codes and Standards	6
4.2 Inspection Findings	
4.2.1 Tank Inspections	7
4.2.2 Participant Responses	10
4.3 Cost Effectiveness	
4.3.1 Equipment Costs	11
4.3.2 Maintenance Costs	11
4.3.3 Energy Costs	12
5.0 Conclusions and Recommendations	
5.1 Codes and Standards	14
5.2 Inspection Findings	14
5.3 Cost Effectiveness	14
5.4 Recommendations	14

APPENDIXES

Inspection Checklist	Appendix "A"
Tank Removal Checklist	Appendix "B"
Zone Schematic	Appendix "C"
Participant List	Appendix "D"
Maintenance Cost Comparison	Appendix "E"
Water Conditioning Study	Appendix "F"
Code Revisions Example Letter	Appendix "G"
Inspection Slides	Appendix "H"
Tank Schematic	Appendix "I"

EXECUTIVE SUMMARY

Introduction

The trend towards energy efficient housing has resulted in significant reductions in the space heating load. As a result, the size and output required for the heating appliances has also decreased, and the domestic hot water load has replaced space heating as the dominant heating load.

Project Objectives

The objectives of this project were to:

1. review the relevant codes and standards and contact appropriate authorities to approve domestic hot water tanks as hydronic space heating appliances in residential applications;

2. determine the state and condition of domestic hot water tanks currently being used as combination hot water and space heating appliances; and

3. analyze the cost effectiveness of utilizing domestic hot water tanks as space heating appliances.

Investigation Method

The Canadian Standards Association and the Canadian Gas Association were contacted for details of the existing codes and standards related to the installation of domestic hot water tanks. Local and national agencies which understand the concerns related to using a domestic hot water tank as a space heater were questioned as to what the concerns are and what should be inspected when the tanks are dissected. The codes and issues relating to the equipment are documented.

This project investigated the state and condition of three domestic hot water tanks that have been in service, in the Northwest Territories for six years, as combination hot water and space heating appliances. Two of the three tanks were dissected in the presence of local officials, while the third tank was shipped directly to the manufacturer so that a thorough inspection could be carried out in their laboratory. An assessment of the overall condition of the tanks, including the degree of deterioration/corrosion of the liner, condition of the burner and the quality of the water was carried out. In addition a radiator and plumbing pipe were examined.

Records of the costs related to the purchase, installation and maintenance of various heating appliances were supplied by the Northwest Territories Housing Corporation. These costs were averaged to determine the operating costs for individual systems.

Conclusions and Recommendations

The standard for the utilization of domestic hot water tanks does not allow for their use as space heaters. If water is to be heated for space heating then a boiler is to be installed according to its installation standard. Authorities reported that the rationale for limiting the use of hot water tanks is related to the increased duty cycle and to the fact that a more suitable product was on the market at the time the standard was developed, namely the hydronic boiler.

The inspection of the domestic hot water tanks showed little evidence of deterioration of the tanks beyond what would be expected after six years of normal service. The glass liners were intact and the anodes remained effective.

The cost analysis showed that the capital, installation and maintenance costs for providing space heating with a domestic hot water tank are lower than those for conventional systems.

Interviews and correspondence with standards officials has lead to the conclusion that a formal application for the revision to the standard should be forwarded along with support documentation to the Canadian Standards Association, Standards Administrator, Mr. B. M. Deibert.

1.0 INTRODUCTION

This paper examines the codes and standards which impede the utilization of a domestic hot water (DHW) tank as a space heating appliance with the intention of providing the foundation for pursuing a revision to the codes.

The Northwest Territories Housing Corporation has at present about 5000 residential units in its inventory, approximately half of which are heated by a hydronic system. The Corporation has in recent years been upgrading the insulation levels in their homes to a point where the domestic hot water energy load is beginning to exceed the space heating load. In response to the shift in dominant heating load the Corporation received temporary code exemption to utilize hot water tanks to provide both types of heating requirements. The primary advantage for the Northwest Territories Housing Corporation is a reduction in capital, installation and maintenance costs over the use of a hydronic boiler system. In order to install additional systems a revision to the existing code must be approved by the Canadian Standards Association.

The intention of the inspection process was to provide information for two separate groups. The Northwest Territories Housing Corporation has an interest in the life expectancy of the tanks when used in a continuous manner. It will be important for them to check for premature deterioration of the tanks, as this will affect the economics of installing these units as against more conventional equipment. The other group interested in the findings of the inspections is the code authority which, both regionally and nationally, are finding that there is pressure to establish a standard by which these, and other tanks, can be approved for use as heating appliances.

2.0 PROJECT OBJECTIVES

The objectives of this project were to:

1. review the relevant codes and standards and contact appropriate authorities to determine the procedure required to have domestic hot water tanks approved as hydronic space heating appliances in residential applications;

2. determine the state and condition of domestic hot water tanks currently being used, in the Northwest Territories, as combination hot water and space heating appliances; and

3. analyze the cost effectiveness of utilizing domestic hot water tanks as space heating appliances, in the Northwest Territories.

3.0 DESCRIPTION OF WORK

3.1 REGULATORY AGENCY INTERVIEWS

Agencies which regulate the manufacture and installation of domestic hot water tanks in Canada were contacted for their insights into the rationale for the existing domestic hot water tank standards (both oil and gas) and for their input into guidelines for inspecting used tanks.

The authorities stated, that the standards were initially developed to provide a consistent level of quality and safety for the manufacture and installation of hot water tanks. When committees were formed to develop the standards, there was no strong consideration or motivation for having DHW tanks approved as space heating appliances. Boilers were considered the appliance of choice because of their higher efficiencies and their ability to meet the typical heating requirements of a house. In addition, the boiler was designed to run continuously over extended periods and, therefore, had several safety features built into its design.

The regulatory authorities generally agreed that DHW tanks are safe and function well, but their primary concern was how an extended firing cycle might affect an appliance with limited safety features.

Initial discussions with regulatory authorities, suggested that no one had a clear idea of what the interior of a dissected domestic hot water tank would look like. All those interviewed envisioned significant accumulations of sediment and the resultant reduction in efficiencies. Beyond the sediment build up and the restriction of plumbing lines, there was no consensus as to the conditions that might exist. All of the authorities contacted supported the inspection that was carried out, and each provided input into what needed to be inspected during the dissection of a DHW tank. Their inspection guidelines were used to develop the *Inspection Checklist* in Appendix "A".

In recent years, the Alberta provincial government has found that the use of domestic hot water tanks as auxiliary space heating appliances has become more popular. The Building Standards Branch does not at this time sanction the use of domestic hot water tanks for this purpose, but it does recognize the fact that they are being used. The Branch has found that individuals are using the tanks to heat everything from farm applications to swimming pools. Due to this prevalent use of the units, the Branch has decided to develop a guideline for installing the units. A committee is presently being established that will meet during the summer of 1989.

3.2 IDENTIFICATION OF TANKS

At present in Canada, there is no record of the number of installations in which a domestic hot water tank is being used for either primary or auxiliary space heating. Regional authorities estimate that there are several hundred of these systems in use across the country. Systems of this type are being used to provide space heating for farm applications, workshops, residential applications and for swimming pools.

The Northwest Territories Housing Corporation has installed between 40 and 50 systems which provide both the space heating and the potable water heating.

Three of these tanks were selected for removal, and subsequently inspected by local authorities. In addition, a section of related plumbing was removed and inspected. The systems chosen for inspection were originally installed in late 1983 by J.& R. Mechanical on a subcontract to the Northwest Territories Housing Corporation.

The tanks were located in housing units built in Dettah Village which is located just outside of the city of Yellowknife. The tanks were removed from housing units addressed as numbers 6, 9, and 10.

Each of the housing units are essentially identical in size and layout. They are all 2-story houses, with approximately 120 square meters of living area. There are no basements as each house is elevated off the ground on piles. The main floor includes the mechanical room and common living area while the second floor incorporates three bedrooms and a bathroom. The insulation values in the floor, walls and ceiling are RSI 7, RSI 4.7 and RSI 10 respectively.

Each of the homes is heated by a John Wood 307 oil-fired domestic hot water tank and an array of radiant baseboard elements. The John Wood 307 is a 30 U.S. gallon tank heated by a Fess model 55K-2X-01 oil fired burner. The maximum consumption of this burner is 0.75 gallons per hour, and the unit requires a 15 cm diameter flue with a 15 cm diameter outside combustion air inlet. The tank services two zones each of which has a radiant baseboard loop of 27 to 30 meters in length.

Installation reports and the combustion efficiencies of the equipment are attached as Appendix "B".

A schematic of the heating zones is attached as Appendix "C", and each zone is made up of the following components.

<u>Second Floor Zone</u>

6 radiant segments @ 1.5 meters and 1524 fins

1 radiant segments @ 1 meter and 914 fins

<u>Main Floor Zone</u>

1 radiant segments @ 4 meters and 4115 fins

1 radiant segments @ 2 meters and 2134 fins

1 radiant segments @ 1.5 meters and 1524 fins

In total, each home has 10 radiant baseboard elements which extend 17.5 meters along the exterior walls. The heat output for the radiant heating system, referenced from the design drawings, is designed to be 10.44 kW.

Water for both the heating system and for general consumption is trucked into the homes from a central municipal water supply. An electric pump is used to draw the potable water from the household reservoir tank and pressurize the plumbing system to 45 pounds per square inch. The DHW tanks use the acting line pressure in normal operation and do not reduce this pressure as does a boiler system.

The inspection of the domestic hot water tanks was carried out in the shop of the mechanical subcontractor, J.& R. Mechanical, on February 28th, 1989.

The exterior shell of the tanks was removed prior to the formal inspection. In the presence of the authorities listed in Appendix "D", 2 of the tanks were carefully cut open at the mid-line using a cutoff saw. The use of a cutting torch was considered but, after discussions with the tank manufacturer, it was determined that the use of the cutoff saw would reduce the damage to the tank.

3.3 COST IMPLICATIONS

For the Northwest Territories Housing Corporation, the economics of utilizing a domestic hot water tank as the primary heating appliance is a complex issue. The equipment options and considerations which have gone into the Corporation's economic analysis are listed below.

a) Equipment Options

- -forced air oil furnaces with separate domestic hot water tank
- -boiler with companion domestic hot water tank
- -domestic hot water tank

b) Considerations

- -capital cost
- -shipping cost
- -installation cost
- -maintenance costs
- -replacement costs
- -space requirement
- -replacement frequency
- -equipment efficiency
- -technical complexity
- -parts availability

The most desirable equipment is that which is the least expensive to purchase, operate and replace as well as requiring the least space. Efficiency, simplicity of design and maintenance requirements should also be considered.

4.0 RESULTS AND DISCUSSION

4.1 CODES AND STANDARDS

The guidelines for use of domestic hot water tanks in Canada are legislated in a number of different codes and standards. Separate standards are established for various fuel types and for both the installation and the manufacture of the tanks.

There is a distinct line of authority and a separate standard for a domestic hot water tank fueled by gas. The authority for this gas appliance is the Canadian Gas Association (CGA). The CGA has both a standard for the manufacture of the tanks which is listed as, "*Gas-fired automatic storage type water heaters with inputs less than 75,000 btu,* and a code for the installation of the equipment which is listed as, "*Natural gas installation code.*"

The authority for the testing and approval of oil-fired domestic hot water tanks rests with the Canadian Standards Association (CSA). They also have a standard for the manufacture and installation of this equipment.

Fuel Type	Manufacturing Standard	Installation Code
Natural Gas	CAN1-4.1 M85	CGA B-149.1 M86
Oil	CSA B-140.12 1976	CSA B-139 1976

A service hot water heater is defined as "*an appliance intended for the heating of water for plumbing services (distinct from water for space heating)*".

The standards for gas fired and oil fired boilers are respectively, CGA 4.9 1969, "*Gas Fired Steam and Hot Water Boilers*" and CSA B140.7.1, "*Oil Fired Steam and Hot Water Boilers for Residential Use*". Within the standards a boiler is defined as an appliance intended to supply hot water or steam for space heating, processing, or power purposes.

The CSA manufacturing standards applicable to the construction of boilers and DHW tanks are different in both the maximum pressures and temperatures under which each can operate. The following table outlines the maximum and normal operating parameters for each system.

Equip. Type	Maximum Pressure	Maximum Temperature	Operating Pressure	Operating Temperature
DHW	150 psi	180 °C	45 psi	140 °C
Boiler	30 psi	220 °C	15 psi	180 °C

4.2 INSPECTION FINDINGS

4.2.1 Tank Inspection

Two tanks were inspected utilizing a checklist (Appendix "A"), which was developed from interviews with CSA officials. A schematic which indicates the points referred to in the inspection findings is attached as Appendix "I". The findings are as follows.

a) Structural Integrity

Research indicates that the corrosive qualities of the water which the system is subjected to play a significant role in the deterioration of a hot water tank. A study of the water which is used by the city of Yellowknife, titled "*WATER CONDITIONING STUDY, CITY OF YELLOWKNIFE*" and authored by Facey and Smith, was completed on November 28, 1988 and is included as Appendix "F". The focus of this report deals with the deterioration of underground water lines, but also lists various qualities of the source water which affect the performance of DHW tanks.

Deterioration of the Anode

- The anodes were found to have eroded from a cylindrical to a conical shape. The actual weight of each anode must be compared to its original weight in order to evaluate its decay. Depending on the make-up and the volume of water that has passed through the tank, the anode can show various degrees of wear. The wear evident on these anodes was normal.

Corrosion of Steel Tank

- There was no evidence of corrosion to the steel tank or the welds in the first tank inspected, but the second tank, with the glass void mentioned below, showed slight signs of rusting. A void of this size is due to the normal heating and cooling cycles of the tank over several years, and would allow for rust formation and eventually a leak in the area.

Make-up of the Glass Liner

- The liner material in the John Wood 307 tank is of a glass enamel material which is applied under intense heat after the tank has been fabricated and the fittings attached. The heat under which the coating is installed causes the steel of the tank to off-gas which in turn creates tiny bubbles in the glass coating. It is these small voids which can be the origin for electrolysis and eventually allow for leaks in the tank shell.

Voids in the Glass Enamel Liner

- The first tank to be inspected showed signs of what appeared to be small bubbles in the glass lining under a fine sediment layer which coated the surface of the liner. This bubbling appeared primarily on the column which formed the flue. The second tank showed no such signs of glass liner breakdown but did have a spot about 3 cm in diameter where the glass liner had flaked away. Ideally the glass liner should provide a continuous coating on the interior of a tank but since this is rarely the case the anode is designed to reduce any rusting of the steel tank. These conditions would be normal for tanks of this service age.

Thickness of the Glass Lining

- There was no visible reduction in the overall thickness of the glass lining other than the bubbling and the one void noted earlier.

Thermostat Settings

- The tanks were all installed with a standard domestic hot water tank thermostat which has settings between vacation and high. All of the tanks thermostats where set in the mid-range, which is normal for DHW tanks.

Deterioration of Fire Pot

- The fire pot or fire chamber is made up of flexible, white, fireproof blanket material which has a tendency to become brittle and crack when exposed to extreme heat over long periods. The fire pot in the two tanks showed very little wear, although hairline cracks had begun to form. These cracks were normal and the fire pot was thought to be in excellent condition.

Burning of the Baffle

- The flue baffle, which slows the flow of combustion gases up the flue allowing more heat transfer to take place, was found to be in excellent condition with only normal discoloration at the lower end. There was no buildup of soot in the flue passage.

Burning Back of Electrodes

- The electrodes which ignite the fuel oil will show signs of wear at their tips after an extended service period. The mechanical contractor responsible for the removal of the tanks indicated that the electrodes showed typical wear and were in good condition.

b) Sediment Build-up

Build-up of Sediment on the Tank Bottom

- A 3-5 mm build-up of a rust colored sediment was evident on the bottom of the tank. This material, renascent of barnacles, was of a lumpy consistency and was well adhered to the tank bottom but not the sides. Sediment build up varies depending on the qualities of the water and the volume circulated.

Precipitates on the Tanks Vertical Walls

- The first tank had a fine film of material on all of its vertical surfaces. This film was of a rust color and was rough in texture. It was easily wiped off the surface uncovering the glass liner beneath. The second tank showed no signs of any film on the vertical surface.

Sediment Build-up on Controls

- There was no evidence of sediment build -up on any of the control mechanisms or on the plumbing lines themselves. The siphon hole, pressure relief valve and the thermostat were clear of sediment.

Without laboratory analysis, the makeup of the sediment and it's effect on water quality cannot be determined.

The second tank had a dent in the bottom of the pressure vessel which was well rounded, covering an area of about 10 cm^2 and indented inwards approximately 1 cm. There was no sign of what might have caused this indentation nor was there evidence that the dent was causing any deterioration to the tank liner.

The third tank which was removed from service was sent directly to the laboratories of the manufacturer G.S.W. Industries in Ontario. Along with this tank, wall samples of the two tanks which were dissected along with their anodes and corresponding name plate were also forwarded for analysis. The manufacturer has agreed to inspect the tanks for wear and attempt to determine the life expectancy of the units. Sections of radiant baseboard will be cut and examined for thinning of the walls and for sediment build up.

A pipe section of thin gauge radiant line and standard gauge copper line, each 2 m long, were also removed and inspected. Neither of these sections showed any signs of wear or sediment build-up.

4.2.2 Participant Responses

The following is a composite of the verbal feedback and individual opinions of the participants (Appendix "D") while present at the inspection of the domestic hot water tanks. These comments are not factual statements but simply derived impressions.

Each of the parties present took interested note of the fact that there was very little sediment build up of any description and that there was no fouling or plugging of the flow lines. The inside of the tank appeared to show little wear. Those participants which were more experienced in the operation of this equipment noticed little or no deterioration to the fire chamber. They had expected to see hardening and cracking of the fire guard insulation blanket which surrounds the chamber. They were impressed that no such condition existed. It was noted that the flue baffle showed only slight discoloration and no noticeable deterioration.

The overall feeling of the participants was that the tanks showed no appreciable deterioration and that no health or safety risk was evident. Specifically it was commented and agreed upon that, other than increasing the duty cycle of the tank and, therefore, reducing its potential life, there is nothing functionally different about how the tank is operated. It was understood, that the increased duty cycle could well cause extensive deterioration of the tank in areas where the source water was particularly corrosive. The water supply in Yellowknife, although considered corrosive, did not seem to have a significant affect on the tanks. There are regions of the country, such as areas in Saskatchewan, with water supplies which are considered extremely corrosive and therefore may not be good candidates for the use of DHW tanks as space heaters.

4.3 COST EFFECTIVENESS

4.3.1 Equipment Costs

The Corporation found from their initial calculations that the use of a domestic hot water tank would be the most effective utilization of resources. Their research showed that the tanks were less expensive to purchase, install and maintain. Both the boiler and the furnace system were heavier than a hot water tank and so the relative cost of shipping locally and to remote areas is more.

In addition, the floor space required by the domestic hot water tank system is considerably less than either of the other two systems. This reduction in required floor space affects the cost of construction in an environment where construction costs are extremely high.

A simple cost comparison for the purchase and installation of a DHW system verses a boiler in the Yellowknife area is as follows.

	BOILER	DHW TANK
Capital Cost	$4334	$2324
Installation Cost	$ 300	$ 160
Shipping Cost	$ 120	$ 45
Total	$4754	$2529

This cost breakdown, as supplied by J&R Mechanical, shows that a DHW system is approximately $2225 less expensive to purchase and install than a boiler system. Both systems are specified to provide potable hot water and space heating.

4.3.2 Maintenance Costs

One of the problems that the Corporation faces is the maintenance of housing units built in remote areas. These units are rented through a local housing authority which has the responsibility of maintaining them with a staff unqualified to handle complex heating systems. Problems with simpler heating systems are easier to troubleshoot and correct. If a tradesman from Yellowknife has to be flown into the remote location to fix a complicated boiler, the cost of the repair increases dramatically.

Although it was never expected that the domestic hot water tanks used for space and potable water heating would last more than five years, it was realized that it would be a less expensive commitment to ship a new tank and get the local authority to install it. This would not be feasible with a boiler system.

The availability of parts is essential when dealing with extremes in climate and the vast area of the NWT. It was found that the parts for a conventional domestic hot water tank were readily available and could easily be shipped and installed, whereas the parts for a boiler were not always available and were often much more difficult to install.

The Northwest Territories Housing Corporation has collected cost comparison data from 410 housing units which they have in their housing stock. It was found that the average cost for maintenance was $280/unit. The heating system breakdown showed that boilers averaged $242/unit, furnaces averaged $298/unit and domestic hot water tanks averaged $90/unit. The corporation has not tracked the costs of DHW space heating systems and therefore only has the costs of conventionally utilized tanks which are lumped with other large household appliances in calculating the $90/unit maintenance cost. A letter outlining the precise breakdown is attached as Appendix "E".

4.3.3 Energy Costs

A serious consideration in determining the cost effectiveness of a heating system is the cost of energy which is necessary to provide the required heat. A simple calculation of these costs are calculated as follows.

Output Heat Energy Cost of Oil = OHECO

$$\text{Dollar Savings} = \frac{\text{OHECO}}{\text{eff. Boiler}} - \frac{\text{OHECO}}{\text{eff. DHW}}$$

$$\text{OHECO} = \text{Oil Used By Heating System} \times \frac{\text{Cost}}{\text{Litre}} \times \text{Eff. of Boiler System}$$

In this case the oil used by a heating system is determined by averaging the fuel consumption records of 32 boilers as supplied by Northwest Territories Housing Corporation. System efficiencies are seasonal efficiencies as supplied by the manufacturer.

$$\text{OHECO} = 2591 \text{ litres} \times \frac{\$0.386}{\text{Litre}} \times 79\%$$

OHECO = $790

$$\text{Dollar Savings} = \frac{\$790}{79\%} - \frac{\$790}{58\%}$$

Dollar Savings by using the more efficient boiler is $362/year.

Simple payback can be determined using the following formula.

$$\text{Simple payback} = \frac{\text{Capital cost increment(Boiler-DHW)}}{\text{Fuel Savings}}$$

$$\text{Simple payback} = \frac{\$2,225}{\$362}$$

Payback can be estimated at approximately 6 years.

A complete life cycle cost analysis is required in order to consider all the factors which as necessary in concluding the most effective system to install.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CODES AND STANDARDS

The present codes and standards for the installation and use of domestic hot water tanks do not allow for their use as space heating appliances. A domestic hot water tank is limited to use as a heater for potable water. If hot water is required for space heating a boiler is deemed the approved type of equipment. A revision to the existing standard can be presented to the CSA Standards Administrator, who will then present it to the appropriate committee. Should the committee favor a revision then the standard is revised accordingly.

5.2 INSPECTION FINDINGS

The inspection of the two tanks showed that there was no abnormal deterioration after six years of service. Sediment had built up to a slight degree in the bottom of the tank but it had not affected the controls or the plumbing lines. The anode was in good shape as was the glass liner. The findings of the DHW tank analysis, which is being carried out by the manufacturer, is not yet available, but will be forwarded to Canada Mortgage and Housing Corporation after preparation.

5.3 COST EFFECTIVENESS

The cost of purchasing and installing a DHW tank space heating system is approximately $2,200 less than the cost of a conventional hydronic boiler system. Excluding the costs of maintenance and including the combustion efficiency factors, indicates that there would be a reduction in purchased energy requirements for the boiler over a DHW system. A simple payback calculation shows that the incremental capital and installation costs for a boiler would be recovered after 6 years.

5.4 RECOMMENDATIONS

5.4.1 Standards Revision

The cost effectiveness and the reliability of using a domestic hot water tank as a space heater indicates that it is appropriate to submit a request for a revision to CSA B-140.12 titled "*Oil Fired Service Water Heaters*". This request for revision would be submitted with support documentation to the Standards Administrator, Canadian Standards Association.

The letter requesting a revision should be sent to:

Mr. B.M. Deibert
Standards Administrator
Canadian Standards Association
#178 Rexdale Boulevard
Rexdale, Ontario
M9W 1R3

This letter, an example of which is attached as Appendix "G", should be accompanied by documentation which supports the revision. Segments, if not this entire report, would be considered pertinent to the standards review as well as findings of the manufacturer.

The manager of the Alberta office of the Canadian Standards Association should be provided with a copy of the submission as his office has offered to pursue a submission for revision. In addition, the local representative for the NWT, which sits on the standards committee, should be made aware of the submission so that he too can be prepared to support the revision. These two authorities are:

Lloyd Morton
Manager
Canadian Standards Association
1707-94 Street
Edmonton, Alberta
T6N 1E6

Ron McRae
Chief Gas Inspector
Gas Safety Section
Justice
Government of the NWT
Yellowknife, NWT
X1A 2L9

5.4.2 Design Improvements

It is also recommended that the manufacturers of domestic hot water tanks improve the design in order to increase both the efficiency and life span of the tanks. Future tank design should incorporate side wall venting where possible.

5.4.3 Further Areas of Work

Strong consideration should be given to areas of work which would round out and add to the scope of this project. It is recommended that the following projects be undertaken.

i) Formal submission, on behalf of the Northwest Territories Housing Corporation, should be made to the Canadian Standards Association to revise the existing standards for the installation of domestic hot water tanks as space heaters.

ii) A complete life cycle cost study of a domestic hot water tank space heating system, compared to both a boiler and a forced air furnace, should be carried out to determine the viability of each system in the north.

iii) Carry out a thorough investigation of efficient heating systems presently on the market and approach manufacturers to determine what design modifications are being undertaken to develop better systems.

APPENDIX "A"

INSPECTION CHECKLIST

INSPECTION CHECKLIST

The inspection of the domestic hot water tanks was carried out with the following concerns in mind.

a) Structural Integrity

- deterioration of the anode
- holidays or voids in the glass enamel liner
- corrosion of steel tank
- weld integrity
- thickness of the glass lining
- make-up of the glass liner
- thermostat settings
- deterioration of fire pot
- burning of the baffle
- burning back of electrodes

b) Sediment Build up

- build up of sediment on the bottom of the tank
- precipitates on the tanks vertical walls
- plugging of the anti-siphon hole
- coating of the thermostat sensor with sediment
- flow restriction to the water lines
- plugging of the pressure relief valve
- sooting of flue passage

APPENDIX "B"

REMOVAL CHECKLIST
FOR
JOHN WOOD DOMESTIC HOT WATER TANKS

howell·mayhew engineering, inc.
15006 · 103 AVENUE
EDMONTON · ALBERTA · T5P 0N8
(403) 484-0478

JOHN WOODS DOMESTIC HOT 2000 WATER TANK
REMOVAL CHECKLIST

HOUSING UNIT # 9
DATE OF SERVICE # 22/02/89
SERVICEMAN K. MILLER

The following should be completed in appropriate detail by the subtrade for each of the houses. All equipment and materials must be accurately labeled so that we can trace is origins.

1. The general condition of the domestic hot water tank.
GOOD

2. The conditions of the area surrounding the tank.
TIDY FREE OF DEBRIS

3. The following about the tank itself.
   size of tank 30 US GAL
   type of burner BESS
   output of burner .25 GAL
   manufacturer of tank JOHN WOODS
   model of tank JW 307
   thermostat setting NORMAL
   size of flue 6"
   source of combustion air UTILITY ROOM
   FRESH AIR DUCTWORK
   other comments OPENING BLOCKED OFF

4. The efficiency of combustion.
69.2 % WITH OLD TANK
NET STACK TEMP 497°C
ADJUSTED BURNER TO
70.3 % ON NEW TANK

howell·mayhew engineering, inc.
15006 • 103 AVENUE
EDMONTON • ALBERTA • T5P 0N8
(403) 484·0478

JOHN WOODS DOMESTIC HOT 2000 WATER TANK REMOVAL CHECKLIST

HOUSING UNIT # 6
DATE OF SERVICE # 22/02/89
SERVICEMAN K. MILLER

The following should be completed in appropriate detail by the subtrade for each of the houses. All equipment and materials must be accurately labeled so that we can trace is origins.

1. The general condition of the domestic hot water tank.
   GOOD

2. The conditions of the area surrounding the tank.
   TIDY FREE OF DEBRIS

3. The following about the tank itself.
   - size of tank 30 US GAL
   - type of burner FESS MOD 55K-2X-01
   - output of burner .75 GAL
   - manufacturer of tank JOHN WOODS
   - model of tank JW 307
   - thermostat setting NORMAL
   - size of flue 6"
   - source of combustion air UTILITY ROOM FRESH AIR DUCTWORK
   - other comments OPENING NOT CAPPED OFF

4. The efficiency of combustion.
   69.2 % WITH OLD TANK
   NET STACK TEMP 493°C
   ADJUSTED BURNER TO 70.4 % ON NEW TANK

howell·mayhew engineering, inc.
15006 · 103 AVENUE
EDMONTON · ALBERTA · T5P 0N8
(403) 484·0476

JOHN WOODS DOMESTIC HOT 2000 WATER TANK
REMOVAL CHECKLIST

HOUSING UNIT # 10
DATE OF SERVICE # 22/02/89
SERVICEMAN K MILLER

The following should be completed in appropriate detail by the subtrade for each of the houses. All equipment and materials must be accurately labeled so that we can trace is origins.

1. The general condition of the domestic hot water tank.
GOOD

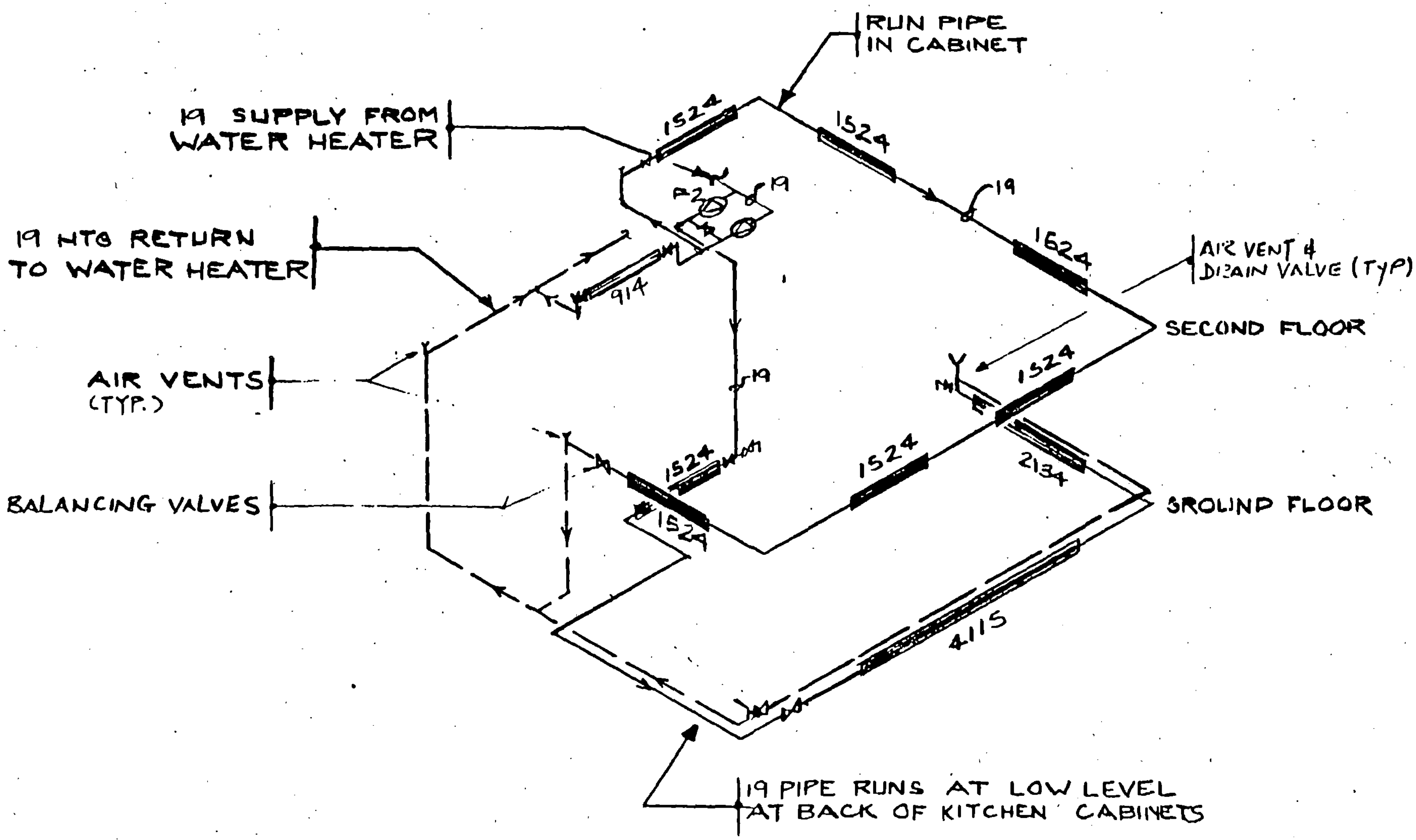
2. The conditions of the area surrounding the tank.
TIDY FREE OF DEBRIS

3. The following about the tank itself.
size of tank 30 GAL US
type of burner BESS MODEL 55K-2X-01
output of burner .075 GAL
manufacturer of tank JOHN WOODS
model of tank JW 309
thermostat setting NORMAL
size of flue 6"
source of combustion air UTILITY ROOM
FRESH AIR DUCTWORK OPENING CAPPED OFF
other comments

4. The efficiency of combustion.
70.3% WITH OLD TANK
NET STACK TEMP 479 °C
ADJUSTED BURNER TO 71%
ON NEW TANK

APPENDIX "C"

ZONE SCHEMATIC



HEATING SYSTEM ISOMETRIC.

APPENDIX "D"

PARTICIPANT LIST

PARTICIPANT LIST

This is a list of people in attendance during the domestic hot water tank inspection.

Mr. Rob Duncan, P.Eng.
Project Manager
Project Implementation Division
Canada Mortgage and Housing Corporation
National Office
Montreal Road
Ottawa, Ontario
K1A-0P7

Mr. Rick Thrall
Howell Mayhew Engineering, Inc.
15006-103 Avenue
Edmonton, Alberta
T5P 0N8

Mr. Dick Bushell
Design/Development Manager
Construction/Development
Northwest Territories Housing Corporation
Box 2100
Yellowknife, NWT
X1A 2P6

Mr. John Butler
Technical Officer
Energy, Mines and Resources
10th Floor, Precambrian Building
4922 - 52nd Street
Yellowknife, NWT
X1A 2N1

Mr. Kit Bell
Fire Marshal
Office of the Fire Marshal
Government of the Northwest Territories
Box 1320
Yellowknife, NWT
X1A 2L9

Mr. R.A. Robinson
Director
Safety Division
Government of the Northwest Territories
Yellowknife, NWT
X1A 2L9

APPENDIX "E"

MAINTENANCE COST COMPARISON

Northwest Territories Housing Corporation

March 14, 1989

CLARENCE EMBERLY,
MANAGER, MAINTENANCE UNIT,
PROPERTY MANAGEMENT & PROGRAM OPERATIONS,
COMMUNITY & PROGRAM SERVICES.

Re: Maintenance Cost Comparison Between Forced Air Furnaces and Hydronics Systems in the Hay River District

Following is the information you requested concerning the maintenance costs of forced air furnaces and boilers.

In compiling this report I extracted data from the HMRS on 410 units covering the period of time from April 1, 1988 to January 31, 1989.

Overall costs were as follows:

UNITS	LABOUR	MATERIAL	CONTRACT	TOTAL	COST PER UNIT
410	$80433	$30702	$3548	$114683	$279.71

Currently we have 42 boilers heating by hydronics 150 Units in the Hay River District. Breakdown of costs are as follows:

UNITS	LABOUR	MATERIAL	CONTRACT	TOTAL	COST PER UNIT
150	$29033	$4719	$3548	$37300	$248.00

Note Included in the labour total is the cost of daily boiler checks

Currently we are heating 260 Units by Forced Air Furnaces in the Hay River District. Breakdown of costs are as follows:

UNITS	LABOUR	MATERIAL	CONTRACT	TOTAL	COST PER UNIT
260	$51400	$25983	NIL	$77383	$297.62

NORthWest Territories Housing Corporation

The information you requested concerning maintenance on Hot Water Heaters cannot be isolated as precisely as Heating Repairs because the HMRS groups water heater along with other major appliances under Activity code 705. For your information here is the breakdown of Activity Code 705:

UNITS	LABOUR	MATERIAL	CONTRACT	TOTAL	COST PER UNIT
410	$13822	$22837	$562	$37271	$90.00

I trust this is the information you require.

Bill Fandrick,
Maintenance Manager,
Hay River District Office

cc Tom Beaulieu
Carl Simms
Gordon Norberg
John Lanskail
Ernie Romans

APPENDIX "F"

WATER CONDITIONING STUDY

WATER CONDITIONING STUDY, CITY OF YELLOWKNIFE

INTERM REPORT

BY

RODERICK M. FACEY

AND

DANIEL W. SMITH

November 28, 1988

TABLE OF CONTENTS

	Page
1.0 Background	4 - 5
2.0 Scope of Work	
3.0 Introduction	6 - 12
4.0 Testing Method	12 - 16
5.0 Interm Results and Discussion	
6.0 Comments	16 - 26
7.0 Appendices	27 - 31
8.0 References	32 - 33

1.0 Background

Presently, the City of Yellowknife obtains its potable water supply from the Yellowknife River. A 8.5 km submarine pipeline is used to pump the raw water to the City and to both the Giant Mine, and the Con Mine. Prior to 1969, the City of Yellowknife, including both mines, obtained water directly from three separate intakes located in the Yellowknife Bay. Gold mining was at the time and still is today, the primary industry in the area, and waste tailings from these mines were continously being discharged to the Yellowknife Bay. As a result of this waste management practice, the potential health hazard associated to the high arsenic concentrations in the waste tailings made it necessary to establish a new location to obtain potable water. In 1969 a new intake was located at the mouth of the Yellowknife River. As a potable water source, the Yellowknife River water is very desireable. Listed in Appendix A are results of analyses for a number of water quality parameters for the Yellowknife River water compared to the Canadian Drinking Water Standards (1987).

The Yellowknife area is characterized as a continental climate, with little opportunity for the dissolution of soil minerals for the limited runoff that does occur. The surface water in this area is low in alkalinity and hardness, being classed as a soft water. On the average the City's potable water has a alkalinity of less than 20 mg/L as $CaCO_3$. The only form of treatment the raw water receives, occurs at pumphouse number one, through the addition of fluoride, chlorine, and during the winter heat.

The City's water distribution system is constructed mostly underground. The distribution piping consists of ductile cast iron, and copper piping. 150 mm diameter ductile cast iron supply lines are used to distribute the water to the central business district and surrounding residential areas. Return lines consist of single 100mm diameter ductile cast iron pipelines. Service line connections consist of 25 mm diameter copper lines.

The only steps taken to protect the distribution system from corrosion are the initial protective coatings present with the pipes as they are installed new. Only the ductile cast iron piping has a protective inside cement lining, and a protective outside tar coating. Unfortunately, the water transported through the distribution system is not only a soft water but is also corrosive to $CaCO_3$ causing the protective cement lining to be dissolved with time. Pipe sections removed from Pumphouse 4 revealed the cement lining as having completely dissloved during a exposure time of less than four years.

As a result of having little or no provisions to combat corrosion, studies have revealed (Stanley, 1986, GCG, 1984) the City of Yellowknife experiencing severe problems with the corrosion of there distribution pipes. In a report prepared by GCG Engineering in 1984, the water was reported as being extremely corrosive, with a Ryznar Index of 12.2. This was further supported by the presence of excess internal deposits of corrosion tubercules in pipe sections removed at Pumphouse 4. Additional evidence of the chemical corrosivity of the Yellowknife River water was reported in the report prepared by Stanley Engineering Associates Ltd (1986). Water samples collected from the river and lake pumphouses showed a marked increase in total iron concentration of 69 percent having occurred between the river intake (Pumphouse no. 2) and Pumphouse no. 1. This increase in the iron concentration between the two pumphouses can only be caused by the corrosion of the unlined steel pipeline. The report by Stanley also reported the water as being very corrosive based on the Caldwell-Lawrence diagram. It is important to note there is no general corrosion index available in today's literature that can accurately asscess the corrosivity of a particular water. The Langelier's Saturation Index, Ryznar's Stability Index, and the Caldwell-Lawrence Water-Conditioning diagrams are all indices related to calcium carbonate. These indices are not by themselves corrosive indices, but are merely indices used to suggest if the water has the tendency to precipitate or dissolve calcium carbonate. Without the support of field tests, these indices cannot be used exclusively to determine the corrosivity of the water. Both consultant reports contain field results which support the conclusion that the water is corrosive.

2.0 Scope of Work

The terms of reference for this water conditioning study can be divided into two phases of work. Phase one of the study, already implemented, involves doing in-situ testing in Yellowknife. The principle objective of Phase 1 is to establish, with reasonable accuracy, the corrosion rate of ductile cast iron and copper used to form the City's distribution system . In addition the study was to assess the degree of the City's corrosion problem in comparsion to other communities with similar problems. Also an effort was made to investigate the methodolody of the experiment to assess the validity of the results.

Phase 2 of the study focuses on doing a laboratory study in Edmonton at the Environmental Engineering Laboratory, University of Alberta, to evaluate the potential for reducing the rate of corrosion using the chemicals listed in Table 2.1. The corrosion inhibitors listed in Table 2.1 will be evaluated, individually and in combination with each other, for there ability to reduce the corrosion rates of both ductile cast iron and copper. The laboratory study has been statistically designed using factorials. The objective of this investigation is to identify the most promising chemical, or chemical combinations for stabilizing Yellowknife's treated water.

TABLE 2.1

Corrosion Inhibitors to be evaluated :

a. sodium hydroxide
b. lime
c. soda ash
d. carbon dixiode
e. sodium silicate
f. polyphosphate
g. zinc orthophosphate

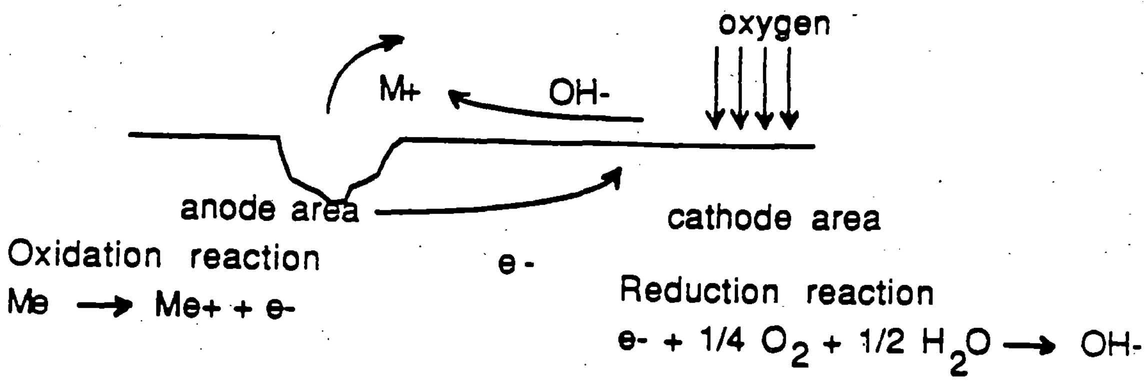
3.0 Introduction

To understand corrosion and to protect against it, requires knowledge of the principles responsible for corrosion. Corrosion is defined as the destructive attack on a material by reaction with the environment resulting in a consequent deterioration of the material's properties. By this definition of corrosion, the material maybe a metal or a cement based product. The term corrosion can be used to imply the process or the damage that is caused. The reaction with the environment to produce corrosion, can be either a chemical or electrochemical reaction. Metal from the corroding material maybe lost by dissolution to the liquid or precipitated as a fused salt on the material's surface.

Internal corrosion of water distribution pipes produces two problems. The most obvious is failure of the pipe. Failure can be the loss of structural integrity of the pipe, causing leakage, or the loss of hydraulic capacity due to excess build up of corrosion products. The second problem, which has prompted concern in the area of health, is the unwanted change of water quality as a result of corrosion products leaching into the water.

When metal is immersed in water the corrosion process is electrochemical. The electrochemical mechanisms responsible for corrosion are described as two separate chemical reactions taking place at different areas on the pipe surface, with the transfer of electrolytic current in the form of ions in solution, and the transfer of electric current in the form of electrons in the metal. Figure 3.1 illustrates schematically the electrochemical mechanisms for corrosion.

FIGURE 3.1
Electrochemical mechanisms for corrosion



The two chemical reactions that occur, do so simultaneously, and at different areas on the surface of the pipe, and cannot occur independently of each other. The two areas where these reactions occur are described as either the anode or the cathode area. At the anode, oxidation of the metal occurs as follows:

$$\text{Metal} \rightarrow \text{Metal}^{n+} + ne^-$$

The metal is oxidized from the metallic state to the ionic state, whereby the valence of the metal is increased by the release of electrons: Metal wastage occurs at the anode, where by the dissolved metal is free to react with the constituents in the water. Three possible secondary reactions iron may undergo to deposit corrosion scales on the metal's surface are listed in Table 3.2.

TABLE 3.2
Corrosion Scales for Iron

(a) $Fe + 2H_2O \rightarrow Fe(OH)_2 + 2H^+ + 2e^-$

(b) $Fe + HCO_3 \rightarrow FeCO_3$ (siderite) $+ H^+ + 2e^-$

(c) $2Fe + 1/2\ O_2 + 4OH^- \rightarrow 2FeOOH$ (geothite) $+ H_2O + 4e^-$

The type of corrosion scale depends on the water quality. For a water low in pH and low in carbonate concentration, reaction (a) of Table 3.2 will occur. When the carbonate cocentration is high, reaction (b) of Table 3.2 occurs. Corrosion scale deposited at the anode can provide a barrier to seperate the water from the metal and cause inhibition of corrosion. At the cathode, the electrons released by the anodic reaction are accepted. The electron acceptor is oxygen for a pH range of 4 to 10 and oxygen is reduced upon accepting these free electrons. Kuch (1984) demonstrated using a clean, fresh steel surface that the active corrosion of iron in oxygenated waters is primarily controlled by the diffusion of oxygen to the corroding metal's surface. Chlorine functions as the electron acceptor. The reduction of chlorine is described as follows:

$$HOCl + H^+ + 2e^- \rightarrow Cl^- + H_2O$$

Chloride ions can promote corrosion of iron based on its ability to form soluble ferrous compounds and thus generate hydrogen ions by reaction with water. The resultant reduction in pH at the anode produces a differential in pH between the anode and cathode. This sets up a corrosion cell, in which the potential gradient between the anodic and cathodic sites increases the rate of corrosion. Figure 3.3 shows the anodic and cathodic reactions for iron that occur as a result of electrochemical corrosion.

FIGURE 3.3

Anodic and cathodic reactions for iron in electrochemical corrosion.

(a) **Anodic Reaction =** $Fe \rightarrow Fe^{2+} + 2e^-$

(b) **Cathodic Reaction =** $1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$

What causes the electrochemical corrosion process to occur? The corrosion of a metal immersed in water will occur if the resulting corrosion product is of a lower free energy than the metal. This difference in free energy is referred to as the driving force. The actual driving force for the process is the potential difference in Gibbs free energy between the anodic and cathodic reaction. The difference in the free energy depends on the type of metal. For example, copper is more noble (releases less free energy) than iron, thus the potential difference is higher for iron. Otherwords, there is a greater tendency for iron to dissolve than for copper. The rate of corrosion is determined by the electrode potential of the particular metal exposed to a particular environment and the kinetics of the reaction.

In order for corrosion to occur, the four steps outlined in the mechanisms for electrochemical corrosion must occur simultaneously. Prevent one of these steps from occuring and corrsion is stopped. To stop corrosion altogether is very expensive, instead the approach normally used is to reduce the corrosion rate to an economically tolerable level has been adopted. To keep corrosion to a level that can be tolerated, requires corrosion protection be incorporated into the design. Often corrosion protection is implemented only after corrosion problems arise.

One method to controlling corrosion is the use of corrosion inhibitors. A corrosion inhibitor, according to the National Association for Corrosion Engineers (NACE) definition(NACE 1970), is a substance which retards corrosion when added to an environment in small concentrations. A broad definition, a corrosion inhibitor applied to protect a system used to deliver potable water, must satisfy the following criteria. These criteria are:

(a) to minimize, to a economically tolerable level, the corrosion damage,

(b) not to change the water quality to affect the health of the consumer, and

(c) not to affect taste, odor, and color.

As a result of these restrictions, the use of corrosion inhibitors in potable water systems is limited and complex.

Corrosion inhibitors reduce corrosion by affecting one or more steps in the electrochemical process. Not all corrosion inhibitors function the same. Corrosion inhibitors can provide protection by anodic control, cathodic control, neutralization, or passivation. Ideally, inhibition of the reaction or step in the corrosion process which is considered rate limiting is the most effective approach to control corrosion.

Anodic control is achieved by the inhibitor reacting with the dissolved metal to form a protective barrier to cover the anode area. This protective barrier is known as a passive film and is often so thin, to measure the thickness requires sophisticated instrumentation. The formation of this passive film is aided by the presence of divalent cations such as zinc, calcium, or manganese.

Cathodic control is similar to anodic control, only the protective barrier is formed covering the cathode area. The protective barrier affects the rate at which oxygen is adsorbed onto the metal surface. examples of anodic and cathodic inhibitors are: phosphates, silicates, and zinc orthophosphate.

Neutralization is a process by which the inhibitor added changes either both or individually the pH and the buffer capacity of the water. Altering the pH can change the potential at the surface of the metal, to make the metal more noble, thereby reducing the driving force responsible for corrosion. A water with low buffer capacity will not adequately be able to neutralize small changes in the hydrogen ion concentration, resulting from reaction by-products or chemical additions, to prevent the pH from changing. Corrosion reactions at the metal interface increase the hydrogen ion concentration locally to to alter the pH. This produces a larger pH differential and a larger driving force for diffusional mass transport to favour corrosion. Examples of neutralizers are; lime, sodium hydroxide, sodium carbonate, and carbon dioxide.

Passivation is another means of controlling corrosion. The inhibitor, when added, shifts the electrochemical potential of the corroding metal into a region where a stable insoluble oxide or hydroxide film forms to protect the metal surface. Example of a passivator is sodium hydroxide.

Potable corrosion inhibitors have a long history of application. Their application has been noted with a range of performance from success to dissmal failure. Success of these inhibitors are site specific and depend very much on the conditions under which they are used. Factors which can effect the performance of these inhibitors are extensive. For example factors such as: temperature, method of application, mixing, type of metal to be protected, presence of corrosion products on the surface of the metal, water quality, inhibitor dose, presence of corrosion accelerators such as chlorine, and dissolved oxygen, are just a few of the many factors which affect the performance of these inhibitors. For this reason a pilot study should be conducted, based on the recommendations of the laboratory study, to further evaluate the performance of the most promising inhibitor or combinations of inhibitors.

4.0 Testing Method

The method selected to evaluate the City's corrosion problem was developed from the study done by Millett (1985). The metal coupon weight loss method is one of several that can be applied. Alternate methods which may be used include methods such as: the Illinois State Water Survey Machined Nipple test, pipe insert method, and the electric resistance measurement method. Of the above methods mentioned, the weight loss method is the most economical and easiest to conduct.

Before conducting laboratory immersion corrosion tests, four criteria need be satisfied. First, the metal coupon samples used in the experiments must be representative of the distribution piping. For this study, actual piping material used in the City's distribution system was cut up to make 50 mm by 25 mm metal coupons. The pipe material used was 150 mm diameter cement lined ductile cast iron and 25 mm diameter Wolverine copper piping.

The second criteria to be satisfied, is the quality of water to which the coupons are exposed to, be the same as that transported in the distribution system. Phase 1 of the study has coupon holding apparatus connected in parallel to the City's main water line. On the average 3500 litres of water is passed through each coupon holding apparatus on a daily basis. Phase 2 of the study involves large quantities of the City's raw water being shipped to Edmonton on a weekly basis. This water will be used in immersion tests to evaluate corrosion inhibitors

The third criteria is the flow velocity should be representative of the flow velocity or turbulence found on the inside boundary of the distribution pipe. The flow velocity to which the coupons are exposed for the experimental setup at Yellowknife is on the average 0.00048 m/s. For Phase 2 of the study, the mixing will be acheived using fine air bubble sand stone diffusers. Utilizing air for the purpose of mixing will not only be sufficient to acheive the turbulent conditons required, but will reduce the cost to using motors and maintain oxygen at its saturated level.

Lastly, the duration of the corrosion test be such that as to allow for the development of corrosion products that will have an important effect on the corrosion rates. Phase one of the study will run for a total of ten months. Phase two of the study will have individual experiments run for a period of twelve weeks.

The method used in this study adheres to the standards provided by ASTM Standard Test Methods (1986). These ASTM Standards are; ASTM G31, ASTM D2688, ASTM G16, and ASTM G4. The corrosion rates will be expressed in units of $g/(m^2\ d)$.

To calculate the corrosion rates, the metal coupons are carefully processed. Before the metal coupons are exposed to the water, the coupons are cleaned according to the cleaning procedure listed in Table 4.1.

TABLE 4.1
Cleaning procedure for metal coupons

SOLUTION	EXPOSURE TIME (Minutes)
a. Carbon Tetrachloride	3-5
b. 2.5% Nitric & HCl acids	2
c. Concentrated HCl acid	1
d. Distilled Water	2
e. Sodium Carbonate 1N	2
f. Distilled Water	2
g. Distilled Water	2
h. Acetone	2
i. Acetone	2

Prior to installment of the metal coupons, the coupons are weighed. Upon removal, the coupons are inspected for pitting, recleaned as done prior to installment, and then reweighed to determine the weight loss. Cleaned with the sample coupons are coupons which have not been exposed to the water. This is done to determine the amount of metal, not corrosion products, that is removed by the cleaning process itself. This amount is then subtracted from the overall mass loss. The equation used to calculate the corrosion rate is as follows;

$$\text{Corrosion Rate } (g/m^2\ d) = (W_1 - W_2)/T \times A$$

W_1 = overall mass loss (g)
W_2 = mass loss of blank (g)
T = time (days)
A = surface area of coupon, does not include coupon edge area, (m^2)

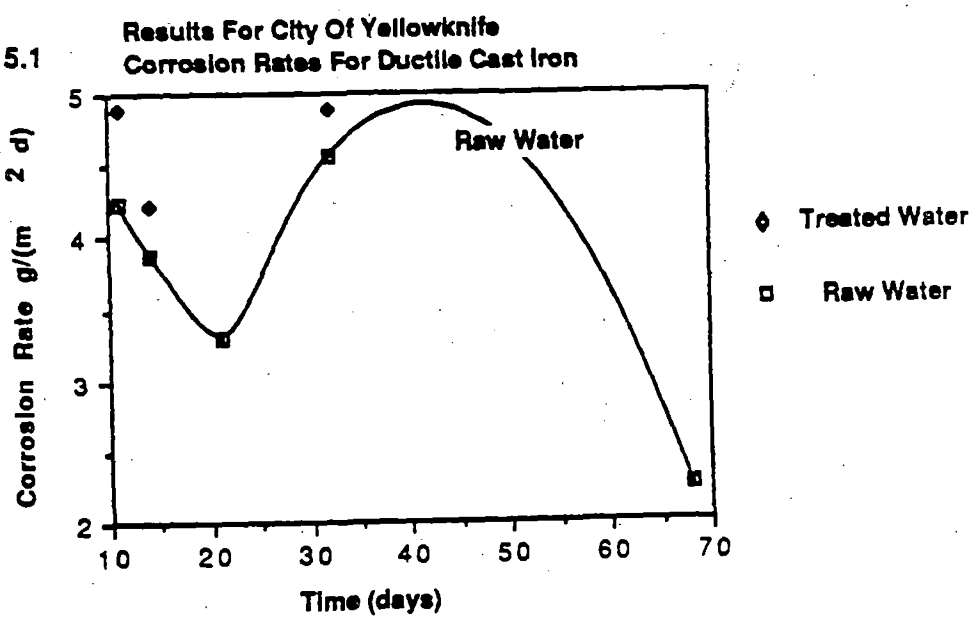
The surface area in the corrosion rate equation does not include the coupon edge area. The coupons were dimensioned as to have a large surface area to edge area, to allow the edge area be neglected.

The coupon method for corrosion measurement is widely used in municipal systems particularly in view of its simplicity as a means to measure the combined effects of all factors of corrosion. Corrosion rates by coupons represent the average conditions. The most serious disadvantage to the weight loss method is for localized attack the calculated corrosion rate will not be representative of the damage to the most strongly corroded portion of the surface. Pitting corrosion must be considered independently. The results of these tests are directly comparable only for the temperature to which the coupon is exposed. The coupon corrosion testing is predominantly designed to investigate general corrosion. Crevices, deposits, or biological growths which may affect local corrosivity need to be considered independently and results interpreted with caution.

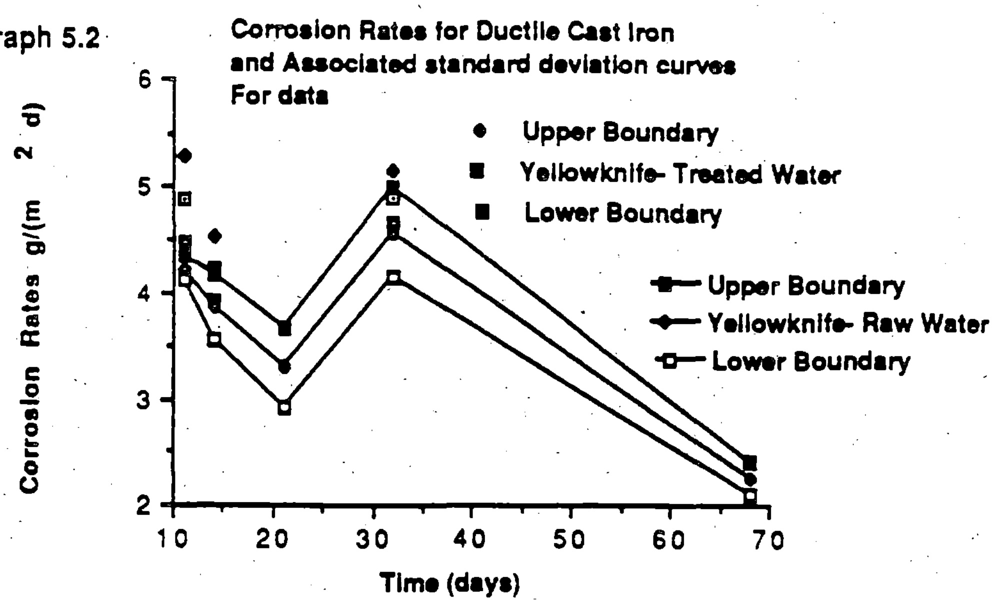
5.0 Interm Results And Discussion

Presented are the interm results for phase one of the study for the City of Yellowknife's raw and treated water. The interm results for the City of Yellowknife are also compared to the results of two past studies. These past studies were conducted by Millett (1985) for the Greater Vancouver Regional District and by Larson and Skold (1957) who experimented with water from the Great Lakes.

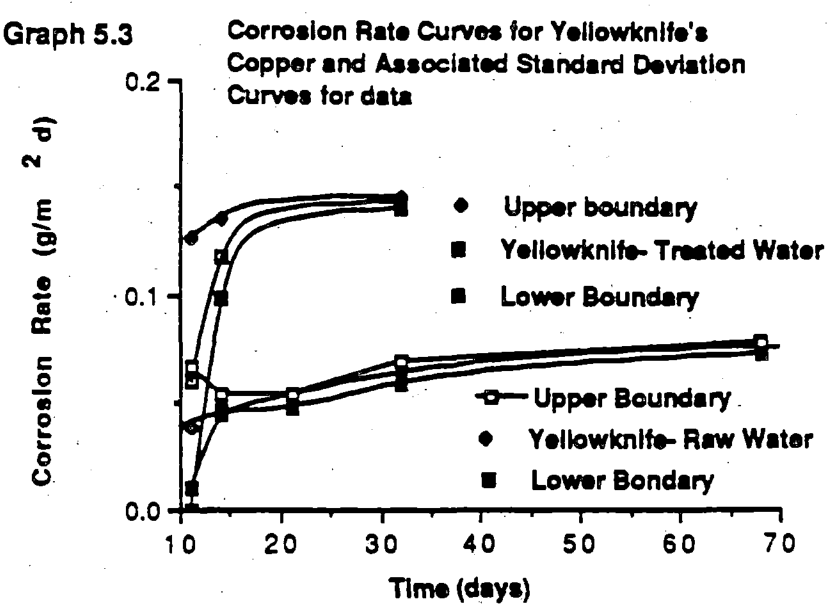
Graph 5.1



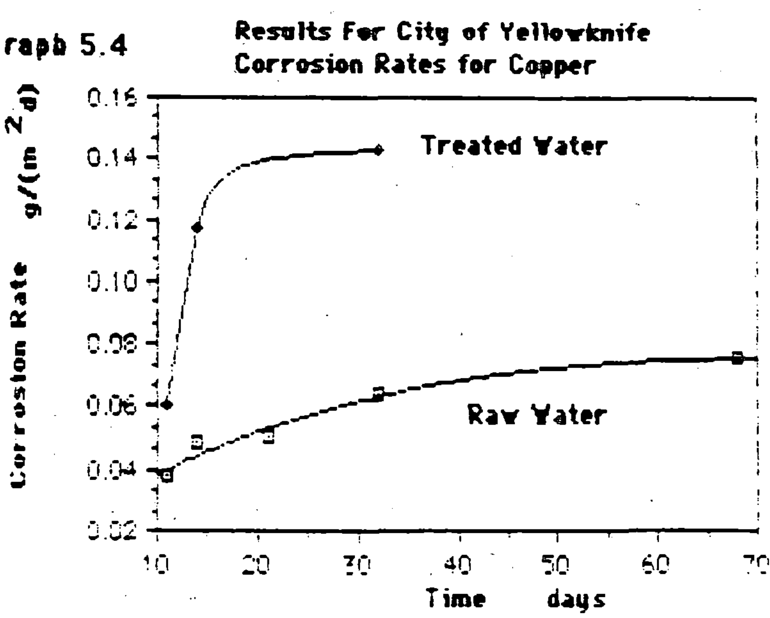
Graph 5.2



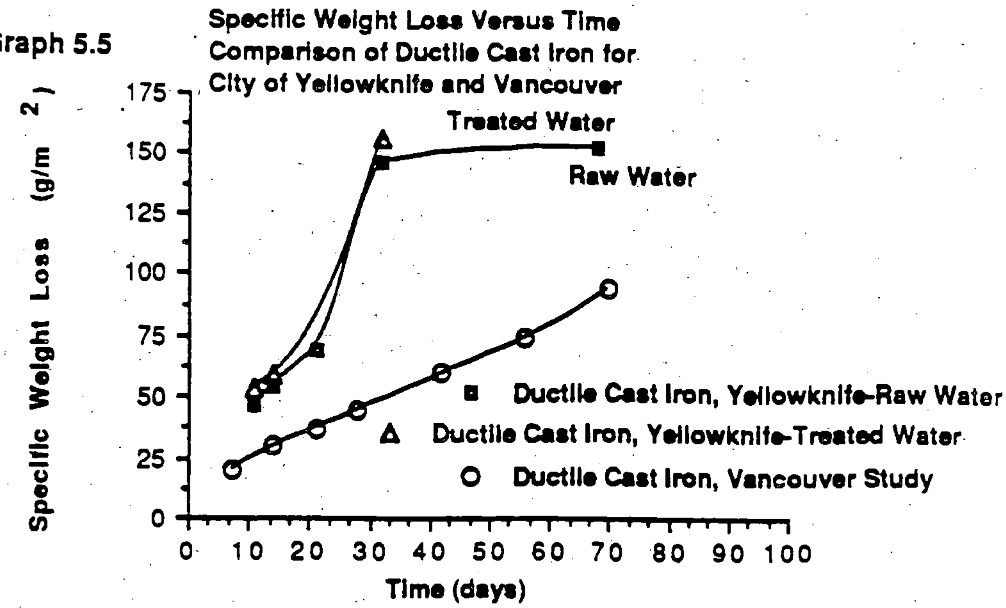
Graph 5.3



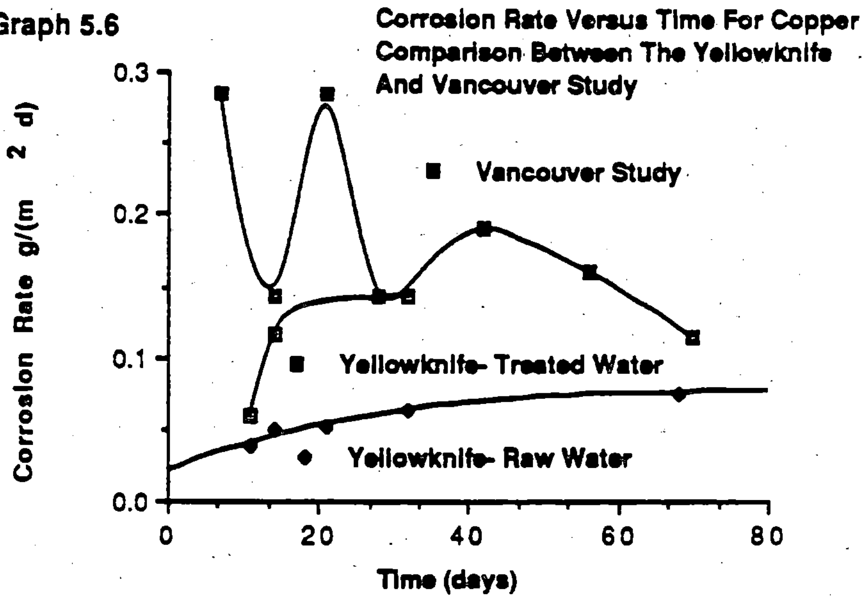
Graph 5.4



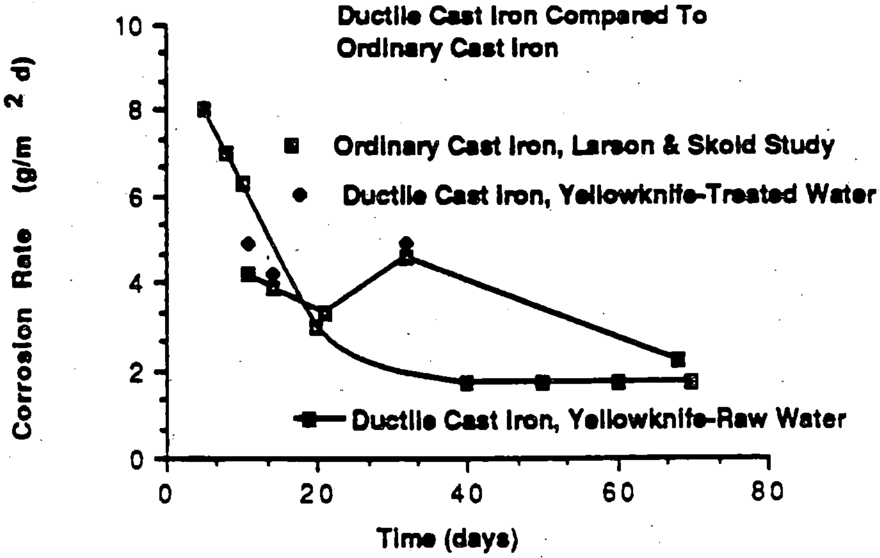
Graph 5.5



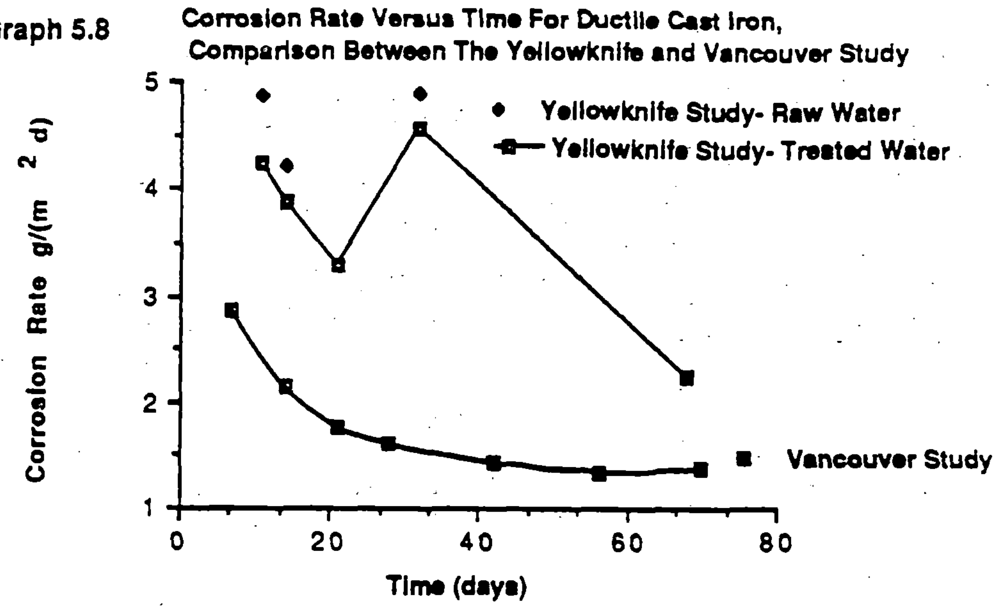
Graph 5.6



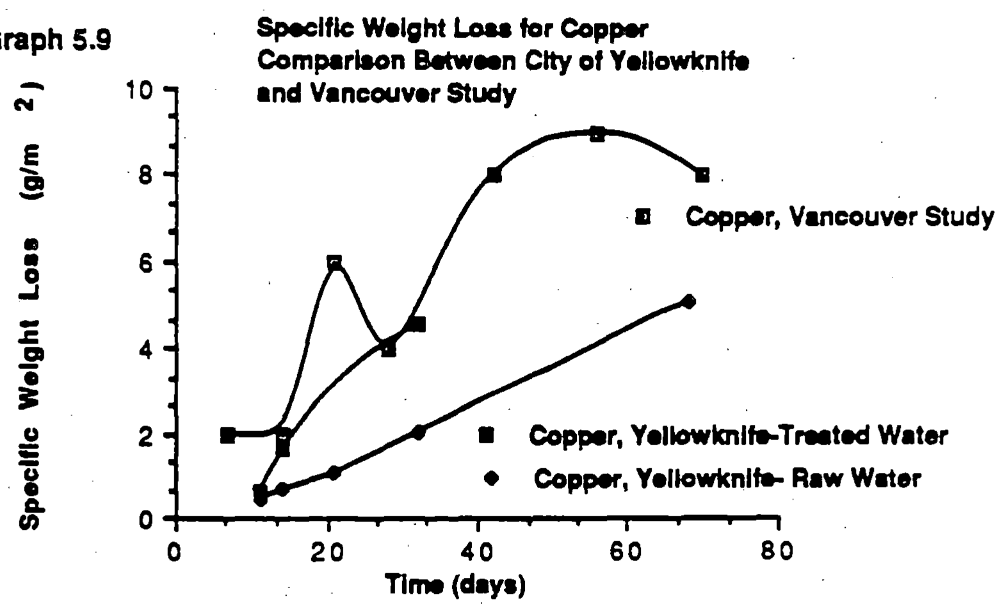
Graph 5.7



Graph 5.8



Graph 5.9



In analyzing the results obtained thus far for Phase 1 of the water conditioning study, the following points are noted. The corrosion rate of copper is only a fraction of the corrosion rate of ductile cast iron for both the City's raw and treated water. Though, as expected, copper has a higher potential than iron, therefore has less tendency to corrode. Both ductile cast iron and copper samples exposed to the City's treated water, show higher rates of corrosion, than those samples exposed to the City's raw water. The corrosion rate of copper for the City's treated water was on the average 2.25 times greater than the corrosion rate of copper exposed to the City's raw water. Ductile cast iron showed similar results, only the magnitude in the difference between the corrosion rates for the City's treated and raw water was not statistically different.

The City of Yellowknife treats its raw water by the adding of fluoride, chlorine, and during the winter heat. During this part of the study heat was not being added. The addition of chlorine to the raw water can attribute to the higher rates of corrosion observed for those samples exposed to the City's treated water. Chlorine acts as a corrosion accelerator. For copper the rate of corrosion is generally uniform. When copper is exposed to dissolved oxygen, a thin film of cuprous oxide is formed on the metal's surface. However, the presence of chloride ions can cause pitting of the metal's surface. Chloride ions tend to promote pitting by increasing the porosity of the protective film of cuprous oxide. Chlorine increases the oxidation of copper and prevents the continuation or establishment of the cuprous oxide film. Suzuki and Ishikawa (1985) found chloride ions affected the formation of cuprous oxide layers, reducing the pit initiation time, and accelerating the pitting process of copper thereafter. Uhlig (1971) showed for drinking water, which falls below the 3% NaCl found in sea water, chlorine will enhance the corrosion of iron. Chlorine can accelerate the rate of attack of iron by the direct increase of the redox potential of the electrolyte that favours the conversion of iron to the soluble ferrous form. Research suggests chlorine or dissloved chlorine species are more powerful cathodic depolarizers than dissolved oxygen. Ductile cast iron samples removed after an exposure time of one month, showed visual signs of pitting. Though not having the instrumentation necessary to evaluate pitting, the depth of pitting could not be asscessed. Copper samples have thus far shown no visual signs of pitting.

Graph 5.1 presents the corrosion rate data for Yellowknife's ductile cast iron for both the treated and raw water. A corrosion rate curve was not fitted to the data obtained for Yellowknife's treated water. The apparatus setup in Pumphouse no. 4 to obtain this data was damaged. As a result, not enough data has been obtained to warrant fitting a curve. Initially, the corrosion rate data decreases rapidly, only to increase again to a maximum at an exposure time of four weeks. Any number of variables or combinations maybe responsible for this fluctuation. A sufficient change in water quality can be significant to affect the corrosion rate. In comparison to the Vancouver study or the study done by Larson and Skold, the environment to which the coupons were exposed to was strictly controlled. Water quality parameters were adjusted in the attempt to achieve a steady state condition. This was not the situation for the in-situ testing in Yellowknife. Water quality data analyzed shows the water quality parameters tend to fluctuate. For example the pH of the water can change by a factor of one. A decrease in pH can be sufficient to increase corrosion.

The error maybe in the results obtained. Graph 5.2 and 5.3 are graphs of the standard deviation curves associated to corrosion rate data. Data points showing large standard deviations is the result of the metal coupons not being properly dried prior to shipment back to Edmonton, where they were analyzed. If the coupons are not properly dried, then the coupons will continue to corrode. Only a thin film of moisture on the coupon surface is needed to serve as the electrolyte to cause corrosion (the rate of corrosion is dependent on the thickness of this film). According to ASTM standards the maximum time the coupons are allowed to remain packaged after removal should not exceed a period of 7 days, when properly dried. The first set of coupons, both the copper and ductile cast iron samples, removed after an exposure time of one week are guilty of this. The set of coupons did not arrive until after a time period of four weeks had passed. Experimental results (listed in Appendix D) have shown samples removed, dried properly, and delivered within four days of removal, did not vary from samples removed and analyzed immediately. Though for samples not properly dried, the corrosion rates had doubled for the same period of time. Coupons having been affected by this showed visual surface marks of black streaks. Samples removed after two weeks of exposure had these characteristic marks to indicate they were not properly dried. Therefore data results for the first two weeks of the study may be questionable. Samples have since been installed to obtain replacement results.

Though the fluctuations in the corrosion rate data could be attribruted to the samples corroding locally. The ductile cast iron samples did show visual signs of local corrosion after an exposure time of four weeks. Local corrosion would cause the specific weight loss curve (Graph 5.5) for the ductile cast iron samples to increase at a non-linear rate. The specific weight loss curves for both the treated and raw water of ductile cast iron increased at non-linear rates.

Fluctuations in the corrosion rate data for copper (Graph 5.4) was not observed. This may be attributed to the differences in the rates of corrosion between copper and ductile cast iron. Changes in the environment will have less effect on a slowly corroding metal, than on a rapidly corroding metal.

Compared are the corrosion rates of ductile cast iron and copper used by both the City of Yellowknife and the Greater Vancouver Regional Dristrict. Also compared is the corrosion rate of ordinary cast iron reported in a study done by Larson and Skold (1957). The rate of corrosion of a metal may be governed by any number of variables, including the minor constituents present in the water. Keeping this in mind, corrosion tests are therefore site specific and valid for the conditions by which the tests were conducted. The comparing the corrosion rates to those reported by other studies, is presented only to assess the degree of Yellowknife's corrosion problem. The differences between the corrosion rates can not be readily explained due to corrosion being affected by so many variables. Listed in Appendix C are a few of the water quality parameters of the three studies compared.

Consider the comparison of the corrosion rates for copper (Graph 5.6) between the City of Yellowknife and the Greater Vancouver Regional District. Comparing only the results for Yellowknife's treated water, the corrosion rates for copper are very similar after an exposure time of five weeks. Initially, the corrosion of copper for the Yellowknife study occurs at a much lower slower rate. The differences in temperature can attribute to this, affecting the rate at which copper is oxidized. Treated water for Yellowknife has an average temperature of 4°C compared to a temperature of 21°C for which the Vancouver study was conducted.

For comparison, the corrosion rates of ductile cast iron for the Yellowknife and Vancouver study are compared. Graph 5.8 shows Yellowknife's ductile cast iron as corroding more rapidly initially, and of a greater magnitude by almost twice the rate reported for the Vancouver study. Graph 5.5, specific weight loss versus time, shows more specifically the weight loss of Yellowknife's ductile cast iron as occuring mostly in the first four weeks of exposure. The sudden decrease in the weight loss after four weeks of exposure, may be the result of the interference the corrosion scales on the metal surface has in terms of affecting the rate at which iron is oxidized. High weight loss over small period of time to cause the corrosion rate curve to go up and down can be indicative of local corrosion, or a significant change in the environment to which the metal is exposed.

For comparison only, the corrosion rate for Yellowknife's ductile cast iron is compared to that of ordinary cast iron (Graph 5.7). The major differences between these two studies are ; the type of metal, and water alkalinity. The Yellowknife water is a soft water with a alkalinity of less than 20 mg/L as $CaCO_3$. compared to a hard water used in the study by Larson and Skold, with a alkalinity of 125 mg/L as $CaCO_3$. Generally, the corrosivity of a water decreases with increasing alkalinity and hardness. Though a soft water, low in alkalinity, in some instances maybe less corrosive than expected due to localized influence pH can have along the inside boundary of the pipe. Graph 5.7, presents the ordinary cast iron is corroding initially higher than for Yellowknife's ductile cast iron.

Ductile cast iron is a type of cast iron which differs from ordinary cast iron with respect to the form and shape of the graphite in the iron. In ductile cast iron, the graphite particles are of a spherical shape, formed by the addition of small amounts of magnesium in the iron.[4] These spherical shaped graphite particles are primarly responsible for the ductility and toughness of the ductile cast iron. Ordinary cast iron is characterized by the major part of the carbon occuring as a graphite in the form of flakes, interspread throughout the iron matrix. The graphite flakes affect the continuity of the iron matrix to introduce notches, to produce the relative weakness and lack of toughness common to ordinary cast iron. Studies have reported ductile cast iron to be more corrosive resistant than ordinary cast iron. Ductile iron has a fundamental advantage over ordinary cast iron, in having a minimun area of graphite and carbides which are potential accelerators of corrosion. The reduced area of the spheroidal graphite and the absence of carbides in the iron matrix of ductile cast iron was shown to have favourable effects in improving corrsion resistance.

Also important to note is all the ductile cast iron coupons used to obtained the results thus far were flatten, as opposed to leaving the coupons in there natural curved state. Flatting the coupons will have cold worked the surface of the coupon to introduce stresses and strains. The effect of cold working a metal will increase the metal's degree of solubility, making it less corrosive resistant. All samples have now been exchanged for curved coupons and tests are being conducted to asscess if having flattened the coupons indeed made the metal less corrosive resistant.

Based on the corrosion rates obtained thus far, if we were to catorgize the ductile cast iron and copper material used in the City of Yellowknife's distribution system on the Ten-point Scale, shown in Appendix B, then the following is noted for the material's corrosion resistance. Ductile cast iron would be listed as a metal exhibiting low resistance to corrosion. Copper would be listed as a highly resistant metal. Though it is important to note the corrosion rate changes considerably with time. As the corrosion products build up on the metal's surface they affect the rate of dissolution of the metal and the diffusion rate of oxygen to the metal's surface to lessen corrosion. The resistance of a metal can be reduced or increased depending on the type of environment it is exposed to. Yellowknife's corrosion results will be compared to additional other studies when more data has been obtained.

6.0 Comments

The following comments are made relative to the results to date:

a. The corrosion problem the City of Yellowknife is experiencing is the result of the corrosion of the ductile cast iron. Ductile cast iron appears to be corroding in some instances at a rate of 75 times greater than copper.

b. Treatment of the raw water with chlorine increases the rates of corrosion for both ductile cast iron and copper. The corrosion of copper is increased by an average of 2.25 times the value reported for the raw water. For ductile cast iron, the difference in the corrosion rates were not statistically different. Though the corrosion rates were higher for the treated water samples.

c. The corrosion rate of ductile cast iron fluctuates with time. This can be the result of local corrosion and a sufficient change in the environment having occured. However coupon handling problems can not be ruled out at this time.

d. Comparison of Yellowknife's corrosion problem to Vancouver's corrosion problem, indicates the City of Yellowknife as having a more serious problem with the corrosion of ductile cast iron. The corrosion of copper is the same or less in favour of the City of Yellowknife.

Appendix A

Water Quality Data For The Yellowknife River

Parameter	Yellowknife River * mg/L except as noted Range	Guidelines For Canadian Drinking Water Standards Max. Acceptable Limits (1987)
pH (pH units)	6.6-7.5	6.5-8.5
Conductivity(umhos/cm)	43-49	defined by dissolved solids
Dissolved Solids	32-44	500
Turbidity (NTU)	0.8-1.8	5
Suspended Solids	LT5	defined by turbidity limit
Colour (colour units)	5-8	15
Calcium	4.1-4.4	not defined
Magnesium	1.5-2.0	not defined
Total Hardness $CaCO_3$	16.5-19	not defined
Total Alkilinity $CaCO_3$	14-15	not defined
Sodium	1.5-1.6	not defined
Potassium	0.9-1.1	not defined
Chloride	1.1-1.2	250
Sulphate	1.8-3.9	500
Total Coli per 100ml	LT1	LT10
Fecal Coli per 100ml	LT1	0
Arsenic	LT0.001	0.050

Cadmium	LT 0.002	0.0050
Copper	LT0.0019	1.0
Iron	0.1080-.0307	0.30
Lead	LT 0.0005	0.050
Mercury	0.00003	0.1010
Nickel	LT 0.0020	not defined
Zinc	0.00513-0.0150	5.0
Chromium	LT 0.0010	0.50

* Yellowknife River water quality data for the period of April 1983 to December 1984.

Appendix B

Water Quality Comparison

Parameter	Yellowknife River Water	Vancouver Test Water (1987)	Larson & Skold (1957)
pH (pH units)	6.8-7.5	7.05-6.95	7.3
Total Acidity mg/L $CaCO_3$	N/A	1.01	N/A
Total Hardness mg/L $CaCO_3$	16.8-19.0	16.49-11.57	N/A
Total Alkalinity mg/L $CaCO_3$	14-15	20.69-15.89	125.0
Calcium mg/L	4.1-4.4	4.72-4.04	N/A
Dissolved Oxygen mg/L	Saturated	11.32-9.31	Saturated
Temperature ,°C	4	21	21
chloride ,mg/L	1.1-1.2	1.15-1.02	N/A

Appendix C

TEN-POINT SCALE OF THE CORROSION RESISTANCE OF METALS
(GOST 5272—50)

Resistance properties	Rate of corrosion (mm/year)	Point
Completely resistant metals	0.001	0
Highly resistant metals	0.001 – 0.005	1
	0.005 – 0.01	2
Resistant metals	0.01 – 0.05	3
	0.05 – 0.1	4
Fairly resistant metals	0.1 – 0.5	5
	0.5 – 1.0	6
Metals exhibiting low resistance	1 – 5	7
	5 – 10	8
Non-resistant metals	above 10	9

Appendix D

Results of the investigation to determine the effect of packaging for an exposure time of five and half days.

Coupon Set	Corrosion Rate g/(m^2d)	Average Corrosion Rate g/(m^2 d)
1- metal coupons removed immediately and analyzed	5.213 5.677	5.445
2- metal coupons removed, dried properly, packaged, and analyzed after 5 1/2 days.	5.434 5.673	5.553
3- metal coupons removed, not properly dried, packaged, and analyzed after 5 1/2 days.	11.145 10.821	10.983

Note- metal coupons used- ductile cast iron (50 mm X 40 mm)

8.0 References

Adeloju, S. B, Hughes, H. C., 1986. The Corrosion of Copper Pipes in High Chloride-Low Carbonate Mains Water. Corrosion Science, Vol 26, pp 851- 870.

Bakhvalov, G.T., Turkovskaya, A.V., 1965. Corrosion And Protection of Metals, Pergamon Press, Oxford, pp 65-100

Community Water & Sanitation Services, 1981. Northwest Territories, pp 223-228.

Dean, R.O, 1968. Corrosion Reactions, Western States Corrosion Seminar, NACE, pp 7-17.

Gabe,D.R. 1983. Coatings For Protection, Institution of Production Engineers, London, 159 pages.

GCG Consulting Engineers, 1984. City of Yellowknife Pumphouse 4 Review of Corrosion Problems And Related Matters, GCG Engineering Partnership Ltd. 15 pages.

Gellings, P.J.,1985. Introduction To Corrosion Prevention And Control. Delft Unversity Press, 136 pages.

Guidelines For Canadian Drinking Water Standards.1987.

Haynes, G.S, Baboian, R. 1983. Laboratory Corrosion Tests And Standards, ASTM Special Technical Publication 866, 597 pages.

Internal Corrosion of Water Distribution Systems. 1983, AWWA, 690 pages.

Kirmeyer, G.J, Logsdon, G. S. ,1983. Principles of Internal Corrosion And Corrosion Monitoring. AWWA, Vol 75, pp 78-83.

La Que, F.L., 1964. Corrosion Characteristics of Ductile Iron. AWWA, Vol 56, pp 1433-1443.

Larson, T.E., King, R. M., 1954. Corrosion by Water at Low Flow Velocity, AWWA, Vol 46, pp 1-9.

Larson, T.E., Skold, R.V., 1957. Corrosion And Tuberculation of Cast Iron. AWWA, Vol 40, pp 1294-1302.

Lane, R. W., 1978. Stabilization Needed To Control Pipe Corrosion And Scale. Water And Sewage Works, July 1978, pp 60-63.

Millette, L., 1985. The Effect Of pH Adjustment On The Internal Corrosion Rates of Cast Iron And Copper Water Distribution Pipes. MSc. Thesis, University of British Columbia, British Columbia, 170 pages.

Nathan, C.C., 1973. Corrosion Inhibitors. NACE, Houston, 261 pages.

Schaschl, E. 1968. An Introduction To Corrosion Principles. Western States Corrosion Seminar, NACE, pp 1-7.

Snoeyink, V.L., Jenkins, D. ,1980. Water Chemistry. John Wiley & Sons, New York, USA, pp 363-376.

Stanley Associates Engineering Ltd., 1986. Water Supply And Treatment Study- Final Report. Stanley Associates Engineering Ltd. Ch 4-5.

Uhlig, H.H., Revie, R.W., 1985. Corrosion And Corrosion Control. third edition,John Wiley & sons, New York, USA, 441 pages.

West, J.M., 1980. Basic Corrosion And Oxidation. John Wiley & Sons, New York, USA, 244 pages.

Wrangler;G., 1985. An Tntroduction To Corrosion And Protection Of Metals. Chapman And Hall Ltd, London, 280 pages.

APPENDIX "G"

CODE REVISIONS EXAMPLE LETTER

month day year

Mr. B.M. Deibert
Standards Administrator
Canadian Standards Association
#178 Rexdale Boulevard
Rexdale, Ontario
M9W 1R3

Dear Mr. Deibert; Re: Revision to CSA B-140.12

The following is a formal request to seek a revision to the existing standard for *"Oil Fired Service Water Heaters"*. At present, the standard limits the utilization of domestic hot water tanks to the heating of water for potable consumption. This request asks that the standard be broadened to allow for the appliance to also be installed as a space heating appliance.

A recent study funded by Canada Mortgage and Housing Corporation and carried out by Howell Mayhew Engineering, Inc. has determined that there is both economic feasibility and consumer demand for the use of domestic hot water tanks as auxiliary and primary space heating appliances. The study, which primarily focuses on systems installed under a code exemption in the Northwest Territories, involved the formal inspection of tanks for structural deterioration and the resultant safety concerns. The findings and recommendations of the report are attached as support to the proposed revision.

The manager for CSA in Edmonton, Lloyd Morton, and the Territorial CSA representative, Mr. Ron McRae, are aware of both the CMHC study and the request for a revision to the existing standard. They have both indicated that they are prepared to support the discussion into a revision to the standard.

For further details or information on this request please contact (the author).

Sincerely yours,

the author

APPENDIX "H"

INSPECTION SLIDES

INSPECTION SLIDES

TANK #1

07- Sediment build up - barnacle type material attached to the bottom of the tank

08- Sediment build up

09 & 10- Anode - this rod is about 2.5 ft long and 1 inch in diameter, and is suspended inwards from the top of the tank

11- Thermostat opening - the thermostat is removed and the area of penetration shows no signs of sediment build up or deterioration

12- Flaking of sedimentary layer on flue - the inside of the flue has a fine film of sediment coating it, the flaking could be this sediment or possibly a layer of the glass liner

13- Flaking of sedimentary layer on flue

14- Siphon hole - this hole shows no signs of being plugged

15- Control inlet - the thermostat is removed and the area of penetration shows no signs of sediment build up or deterioration

17- Sedimentary film on tank side - a thin film of sediment has coated the glass liner of the tank

18- Sooting at burner connection - black soot has built up at the connection between the burner and the tank

19- Base fire blanket in fire pot - the white fire blanket insulation shows normal signs of wear

21- Fire pot bottom and side through burner hole - the white fire blanket insulation shows normal signs of wear

22- Fire pot backside - the white fire blanket insulation shows normal signs of wear

23- Bottom of vessel through fire pot - the bottom is discolored but is sound

APPENDIX "I"

TANK SCHEMATIC

TANK SCHEMATIC

ITEM NUMBER	DESCRIPTION
1	Casing Top Pan
2	Casing Body
3	Casing Bottom Pan
4	Aquastat
5	Flue Baffle Assembly
6	Anode Assembly
7	Glass Liner
8	Fire Pot
9	Drain Valve Head
10	Jacket Insulation
11	Fire Blanket Insulation
A	Indentation in tank
B	Surfaces with Sediment Film
C	Lumpy Sediment build up
D	Void in Glass Liner
E	Bubbling of Glass Liner
F	Fine Cracks in Fire Blanket

HOT WATER TANK SCHEMATIC