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# The Behavior of Asbestos-Cement Pipe Under Various Water Quality Conditions

## A Progress Report

## Part 1 - Experimental Results

by

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# The Behavior of Asbestos-Cement Pipe Under Various Water Quality Conditions

## A Progress Report

## INTRODUCTION

Because of concern about the potential problem of asbestos fibers being released from the walls of asbestos-cement (A/C) pipe the American Water Works Association Research Foundation reviewed the problem of asbestos in water, specifically with relation to the use of asbestos-cement (A/C) pipe. A committee of six recognized experts in the field was convened and their report published in September, 1974 as part 2 of that month's Journal of the American Water Works Association. Appendix F of that report contained 11 Research Needs related to the question "Does the use of asbestos-cement pipe in the (sic) potable water systems constitute a health hazard?"

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## APPROACH

As a response to this call for research, several projects were designed to determine whether A/C pipe would be attacked and asbestos fibers would be released from the pipe under various conditions of water quality. In general, this research has been divided into four phases. One, a specific field evaluation was made of 10 public water supply systems that used A/C pipe and covered a sizeable water quality range, two, an A/C pipe loop was operated under controlled conditions, three, several A/C coupon tests have been made, and four, two field research projects are attempting to rehabilitate deteriorated

A/C pipe in place. Each Phase will be reported separately followed by a general discussion.

## AGGRESSIVE INDEX

The AWWA Standard C400-77[1] establishes criteria for determining the quality of water that can be transported through A/C pipe without any adverse effects. These criteria are:

(a) Non-aggressive: Use either Type I or Type II pipe where pH + log (AH) $\geq$ 12.0

(b) Moderately aggressive: Use Type II where pH + log (AH) = 10.0 - 11.9

(c) Highly aggressive: pH + log (AH) $\leq$ 10.0 - Serviceability of pipe must be established

Where:

pH = index of acidity or alkalinity of the water in standard pH units

A = the total alkalinity in mg/L as $CaCO_3$

H = the calcium hardness in mg/L as $CaCO_3$

Type II A/C pipe is autoclaved and Type I is not.

## RESULTS

### Field Evaluations

Table 1 lists the ten selected systems that were studied, their water quality characteristics and the calculated Aggressive Index (A.I.) of each. The samples for asbestos fiber counts were collected by local water utility or water supply regulatory personnel. They were collected in 1 qt. (946 mL) cubitainers, preserved with mercuric chloride and shipped to EPA Drinking Water

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Table 1. Water Quality Parameters* for Systems Evaluated

| System | pH | Alkalinity mg/L as $CaCO_3$ | Calcium Hardness mg/L as $CaCO_3$ | Initial Aggressive Index (A.I.) |
|---|---|---|---|---|
| A** | 5.2 | 1.0 | 1.4 | 5.34 |
| B | 7.2 | 14 | 14.5 | 9.51 |
| C | 7.5 | 88 | 82 | 11.56 |
| D | 7.8 | 220 | 250 | 12.54 |
| E | 9.4 | 50 | 44 | 12.74 |
| F | 9.7 | 36 | 39 | 12.85 |
| G | 8.3 | 20 | 7.5 | 10.48 |
| H | 7.1 | 89 | 0.5 | 8.74 |
| I | 6.0 | 4.0 | 7.5 | 7.46 |
| J | 4.8 | 3.0 | 2.5 | 5.67 |

*First sampling of each study.

**Before receiving lime treatment.

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Research Division, Cincinnati, Ohio for electron microscopic examination[2,3] In general, precision data indicates that individual fiber counts are within a factor of three of the true value. Fiber count data are reported three ways, as a count in millions of fibers per liter (MFL), a not statistically significant count (NSS) when a few fibers were found, but not enough upon which to base an accurate count, and below detectable limit (BDL) when no fibers were seen. The findings pertaining to each of the ten systems will be reviewed individually.

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System A

System A is part of a larger water utility that has a water us range of 20-25 mgd (75,000- 94,600 $m^3/d$) in winter and 30-40 mgd (113,500-151,400 $m^3/d$) in summer. The population served by the utility is estimated to be 200,000.

The source of the water is wells spread throughout the service area. The water as pumped from these wells is very corrosive or aggressive and will attack all common plumbing materials except plastic. Some of the chemical qualities of the water that make it so aggressive are pH 5.2, calcium hardness 1.4 mg/L as $CaCO_3$ and alkalinity 1 mg/L as $CaCO_3$ which results in an initial Aggressive Index of 5.34, (Table 1). According to Standard C400-77[1] this quality of water is unsatisfactory for the use of A/C pipe because the Aggressive Index is less than 10. A/C pipe was used because A/C pipe was believed not to have the corrosion problems that were experienced with metal pipe. Lime treatment is being applied at each individual well site in an effort to control the corrosion but the lime treatment has not been applied consistently and this has reduced its effectivness.

One section of the system is of special interest. This portion of the overall network was originally privately owned, initiated in 1957 and added on to through 1968. Much of the distribution piping was of A/C pipe, 63,386 feet (19,320 m) was in place when acquired by the municipality in 1968.

Prior to municipal ownership of System A, considerable deterioration of some A/C pipe occurred. Problems with the A/C pipe surfaced in 1964 through customer complaints of water-borne fibers. The problem continued until a short time after stabilization treatment had been instituted. Clogged customer meters and problems at a coin-operated laundry were attributed to fiber accumulation. After lime treatment had been started on a continuous basis, the system flushed and interconnected with the overall city system, consumer complaints subsided and clogging problems were either overcome or not reported. In June 1974, however, in response to a consumer complaint, a collection of visible fibers was obtained from a kitchen faucet strainer. The fibers were identified as asbestos by the U.S. EPA in Cincinnati.

Some time later (January 1975) water samples for asbestos analysis were collected from 3 locations in the system, (1) from the original well supply (2) a location in the older portion of the system (Sample Point 1) and, (3) a location in the newest portion of the system (Sample Point 2). The absence of asbestos fibers in the well samples indicated that the asbestos fibers found in the distribution system resulted from the action of corrosive water on the A/C pipe. As previously indicated, the well water is extremely corrosive having an Aggressive Index of 5.34. The lime treated water in the distribution samples also qualifies as a corrosive water at times, however, with a pH range of 6.4 to 9.3. Although sufficient water quality data are not available to calculate the increase in Aggressive Index during distribution, it was at least 1.8 to 3.8 units higher at the two downstream sampling stations as noted by

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the increase in pH. The increase in pH as the water flowed through the A/C pipe indicated that the pipe was serving as a source of pH adjustment. As the pH rises because of leaching of cementing material from the A/C pipe the water becomes less aggressive to the pipe that follows.

The most likely path water would travel to reach Sample Point 1 would be through 1350 ft (410 m) of 6 in (15 cm) A/C and 655 ft (200 m) of 2 in (5 cm) galvanized pipe. A likely path for much of the water reaching Sample Point 2 would be through 200 ft (61 m) of 10 in (25 cm), 1520 ft (460 m) of 8 in (20 cm) and 10,100 ft (3080 m) of 6 in (15 cm) A/C pipe. The pipe-lines along these routes are all between 15 and 18 years old, having been installed between January 1958 and September 1960. This was Type II pipe manufactured by Johns-Manville and Keesby-Mattison, now Certain-teed.

The chrysotile fibers ranged from 0.3 to 40 um in length and from 0.02 to 0.5 um in diameter although most were single fibrils of no greater than about 0.06 um in diameter. Approximately 75 percent of the fibers were under 5.0 um in length. The median length was 2.0 um. Most samples contained too few amphibole fibers to be able to count accurately. If all the amphiboles found in all the pipe samples are taken as a group, however, the amphibole fiber length ranged from 0.7 to 60 um in length with a median of 2.5 um and with diameters of 0.1 to 0.2 um.

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As indicated in Table 2, asbestos fibers were found regularly in the samples taken from System A. Interpretation of fiber data such as contained in Table 2 must be made cautiously because the presence of fibers in water may be caused by drilling and tapping as well as release of fibers from the pipe walls or fibers contained in jointing materials. In this case, however, little doubt existed that much of the fiber count in this system came from deteriorated pipe because inspection of removed sections of pipe showed them to be in badly deteriorated condition.

System B

System B had an average water use of 1.6 mgd (5,960 $m^3/d$) in 1975. The population served is estimated at 20,000. The water is purchased from a municipal system with a surface supply. The pH is 7.2, alkalinity is 14 mg/L as $CaCO_3$, and calcium hardness is 14.5 mg/L as $CaCO_3$ resulting in an initial Aggressive Index of 9.51 (Table 1). The only treatment of the water is chlorination for disinfection and fluoridation for prevention of dental caries.

The path of flow to Sample Point 1 probably traverses 3,435 ft (1050 m) of 10 in (25 cm) and 2,655 (810 m) of 8 in (20 cm) A/C pipe for a total A/C pipe length of 6,090 ft (1860 m). The flow path to Sample Point 2 probably traverses 8,520 ft (2600 m) of 12 in (30 cm), 5,930 (1810 m) of 10 in (25 cm), 10,100 ft (3080 m) of 8 in (20 cm), and 6,570 ft (2000 m) of 6 in (15 cm) A/C pipe for an overall distance of 32,110 ft (9790 m) of A/C pipe. Most of the pipe is Johns-Manville Class 150 Type II, but 600 ft (180 m) of Belgium manufactured pipe (Type II) is included. This pipe was all installed from 1965 to 1967.

Table 3 shows the asbestos fiber counts from samples taken from

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Table 2. Asbestos Fiber counts for System A

| Date of Sample | Sample Points | | | | | |
|---|---|---|---|---|---|---|
| | Well pH 5.2 A.I. 5.34 | | 1 pH 7.0 A.I. ≥7.14 | | 2 pH 9.0 A.I. ≥9.14 | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL |
| 1/17/75 | BDL | 0.2 | 0.1 | 1.7 | 0.2 | 1.2 |
| 2/1/75 | BDL | NSS | NSS | 33 | BDL | 0.4 |
| 3/26/75 | BDL | NSS | NSS | 1.7 | BDL | 0.3 |
| 5/9/75 | BDL | NSS | BDL | 1.2 | BDL | 0.7 |
| 7/7/75 | BDL | NSS | NSS | 0.7 | BDL | 0.1 |
| 9/5/75 | BDL | NSS | NSS | 0.2 | BDL | BDL |
| 12/4/75 | BDL | BDL | BDL | 0.4 | BDL | BDL |
| 12/8/77 | BDL | NSS | BDL | NSS | NSS | NSS |
| 1/29/79 | x | x | 0.1 | 0.7 | x | x |

BDL (Below detection limit) NSS (Not statistically significant) MFL (Million fibers per liter)

x = Not counted



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Table 3. Asbestos Fiber Counts for System B

| Date of Sample | Sample Point | | | | | |
|---|---|---|---|---|---|---|
| | Control Works pH 7.2, Ca 5.8 mg/L as $CaCO_3$ Alkalinity 14 mg/L as $CaCO_3$ A.I. = 9.51 | | 1 pH 7.6, Ca 8.0 mg/L as $CaCO_3$ Alkalinity 18.8 mg/L as $CaCO_3$ A.I. = 10.17 | | 2 pH 9.0, Ca 11.0 mg/L as $CaCO_3$ Alkalinity 24.6 mg/L as $CaCO_3$ A.I. = 11.78 | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL |
| 2/26/75 | NSS | NSS | NSS | 0.2 | NSS | 0.4 |
| 4/29/75 | BDL | NSS | NSS | NSS | NSS | 0.7 |
| 5/27/75 | NSS | NSS | NSS | NSS | NSS | 1.6 |
| 7/29/75 | NSS | NSS | NSS | 0.5 | NSS | 0.7 |
| 8/26/75 | NSS | NSS | BDL | BDL | BDL | 0.9 |
| 9/30/75 | BDL | NSS | BDL | NSS | BDL | NSS |
| 11/18/75 | NSS | NSS | NSS | 0.2 | 0.1 | 0.3 |

BDL (Below detection limit) NSS (Not statistically significant) MFL (Million fibers per liter)



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system B. No chrysotile fibers were found in the source water samples, although a few amphibole actinolite-tremolite fibers presumably from native rock sources, were found. Three samples from Sample Point 1 contained chrysotile fibers. All but one of the samples from Sample Point 2 contained chrysotile fibers. The water has a fairly short retention time from the source to Sample Point 1. This is partially because of the relatively short distance of 6,090 ft (1860 m) of A/C pipe in which the water travels, but mainly because of the high flow, as this line serves as a feeder line to the distribution system and a 3 million gallon (11,360 $m^3$) storage tank. The water at Sample Point 2 has a much longer retention time because it probably flows through 32,100 ft (9,780 m) of A/C pipe and also because it serves only the needs of customers in this section of the system. The effect of these detention times is evident in the pH values.

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The pH change from the source to Sample Point 1 is about 0.5 units and to Sample Point 2 is about 2 units. This increase in pH as well as the increase in the calcium concentration and alkalinity (Table 3) indicates that the A/C pipe is serving as the source for pH adjustment and stabilization of the water in the system. As the pipe is sacrificed to provide this pH adjustment and stabilization, asbestos fibers can be freed from their cement bond through dissolution of the calcium compounds. The higher asbestos fiber counts at Sample Point 2 appear to be related to an additive effect of the length of A/C pipe traversed. Inspection of A/C pipe exposed to this water showed deterioration and loosened fibers.

The chrysotile fiber lengths ranged from 0.2 to 10 um in length and from 0.02 to 0.06 um in diameter. Approximately 95 percent were under 5.0 um. The median length was 1.0 um. Most samples contained too few amphibole fibers to count accurately. If all of the amphiboles found (13) in all of the pipe samples (14) are taken as a group, however, the amphibole fiber length ranged from 0.7 to 15.0 um with a median length of 2.0 um and with a diameter of 0.1 to 0.2 um.

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System C

System C is a private system which is owned and operated by the users. The daily water use is about 12,000 gallons per day (45 $m^3/d$) serving 41 customers (about 160 people). The water, from a well source, is given no treatment. The well water quality is pH 7.5, calcium hardness of 82 mg/L as $CaCO_3$ and alkalinity of 88 mg/L as $CaCO_3$ that results in initial Aggressive Index of 11.56 (Table 1).

Sample Point 1 has 550 ft (170 m ) of 4 in. (10 cm) A/C pipe and 500 ft (150 m) of 2-1/2 in (6 cm) galvanized pipe connecting it

to the well. Fourteen services are tapped off of this line. The A/C pipe is Johns-Manville Class 150, Type II installed in 1949.

Sample Point 2 can be supplied by two routes that form a loop. One consists of 950 ft (290 m) of 4 in (10 cm) A/C pipe and 400 ft (120 m) of 2-1/2 inch (6 cm) galvanized pipe. The other consists of 700 ft (220 m) of 4 in (10 cm) A/C pipe and 1,000 ft (305 m) of 2-1/2 in (6 cm) galvanized pipe. The A/C pipe manufacturer is the same as described for the other sampling point. Twenty-seven services are tapped off of this loop. The general absence of asbestos fibers (Table 4) in the samples taken from this system is attributed to the moderately aggressive water conditions as indicated by the Aggressive Index. This pipe was not inspected.

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Table 4. Asbestos Fiber Counts for System C

| Date of Sample | Sample Point | | | | | |
|---|---|---|---|---|---|---|
| | Well Pump A.I. = 11.56 | | 1 A.I. = x | | 2 A.I. = x | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL |
| 2/6/75 | BDL | 0.1 | BDL | BDL | BDL | NSS |
| 3/4/75 | BDL | BDL | BDL | 0.2 | BDL | NSS |
| 4/30/75 | BDL | BDL | BDL | NSS | BDL | NSS |
| 7/31/75 | BDL | BDL | BDL | NSS | BDL | 0.2 |
| 10/7/75 | BDL | BDL | BDL | BDL | BDL | NSS |
| 12/9/75 | BDL | BDL | BDL | BDL | BDL | BDL |

BDL (Below detection limits)

NSS (Not statistically significant)

MFL (Million fibers per liter)

x = Not Determined

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System D

The daily water use for System D averages about 0.5 mgd (1890 $m^3/d$) serving 2000 customers (about 7,300 persons). The water source is 4 wells about 30 ft (9 m) deep.

The raw well water hardness is 580 mg/L as $CaCO_3$. This causes some instances of calcium carbonate deposition in water heaters and fixtures but causes no difficulties in operating the treatment facilities and the distribution system. The raw water contains iron in excess of 1.5 mg/L and at times enough manganese to be troublesome. The treatment given the water is aeration, filtration for iron and manganese removal, and chlorination for disinfection. The iron is reduced to about 0.3 mg/L in the finished water. The finished water quality is pH 7.8, calcium hardness of 250 mg/L as $CaCO_3$, and alkalinity of 220 mg/L as $CaCO_3$ which results in an initial Aggressive Index of 12.54 (Table 1).

The 12 in (30 cm) A/C main from which the samples are taken is principally a transmission line from the treatment plant to elevated storage. Only a few residential taps come off this main and no service laterals. The A/C pipe is Johns-Manville Class 150, Type II installed in 1956. The water passes through 5,400 ft (1650 m) of 12 in (30 cm) A/C pipe to reach Sample Point 1 and 9,800 ft (2,990 m) of 12 in (30 cm) A/C pipe to reach Sample Point 2.

The absence of asbestos fibers (Table 5) in the samples from this system is because of the non-aggressive water that has deposition rather than corrosive tendencies. This pipe was not inspected.

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Table 5. Asbestos Fiber Counts from System D

| Date of Sample | Sample Points | | | | | |
|---|---|---|---|---|---|---|
| | Treatment Plant A.I. = 12.54 | | 1 A.I. = x | | 2 A.I. = x | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL |
| 6/4/75 | BDL | NSS | BDL | BDL | BDL | BDL |
| 7/8/75 | BDL | BDL | BDL | BDL | BDL | BDL |
| 9/26/75 | BDL | BDL | BDL | BDL | BDL | BDL |
| 11/24/75 | BDL | BDL | BDL | BDL | BDL | BDL |
| 4/27/76 | BDL | BDL | NSS | NSS | BDL | NSS |

BDL (Below detection limit)

NSS (Not statistically significant)

MFL (Million fibers per liter)

x = Not determined

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System E

System E has an average water use range of 1 - 1.5 mgd (3,790 - 5,680 $m^3/d$) and serves a population of about 7,200. The water source is 4 wells ranging from 302 to 365 ft (92 to 111 m) in depth. Some of the pertinent water quality parameters for these wells are in the following Table 6:

Table 6. Water Quality of System E

| Well Number | pH | Mn mg/L | Fe mg/L | Total Alk. mg/L as $CaCO_3$ | Hardness mg/L as $CaCO_3$ |
|---|---|---|---|---|---|
| 3 | 7.7 | 0.19 | 1.80 | 191 | 304 (Total) |
| 4 | 7.5 | 0.15 | 1.24 | 171 | 216 (Total) |
| 5 | 7.3 | 0.20 | 1.06 | 188 | 263 (Total) |
| 6 | 7.9 | 0.05 | 0.02 | 320 | 46 (Total) |
| Finished Water | | | | | |
| | 9.4 | - | - | 50 | 44 (Calcium as $CaCO_3$)<br>12.74 (A.I.) |

As can be noted, Well No.6 has different characteristics than the other three wells. It is located 6 miles (10 km) east of the city while the other three are about 10 miles (16 km) east of the city. The better mineral quality of well No. 6 is offset by a hydrogen sulfide problem.

The water from the 4 wells is pumped to a treatment facility at the outskirts of the city. The treatment consists of aeration, lime softening, filtration and disinfection. The tray type aeration was originally used for hydrogen sulfide removal, but now serves in the iron and manganese removal process as well. Lime softening with ferric sulfate addition to aid coagulation does not perform satisfactorily. Sedimentation

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is incomplete and deposition of calcium carbonate occurs in the filters and the distribution system. Treatment plant improvements are planned to correct this situation. Disinfection is accomplished by chlorination with the addition of ammonia to obtain a combined chlorine residual. The treated water with a pH 9.4, calcium hardness of 44 mg/L as $CaCO_3$ and alkalinity of 50 mg/L as $CaCO_3$ results in an Aggressive Index of 12.74 (Table 1).

Sample Point 1 is at the end of a three mile (5 km) combination of 6 and 8 inch (15 and 20 cm) diameter A/C pipe. The pipe is Johns-Manville Class 150, Type II installed in 1954-55. Some services are tapped off this line, but mainly it serves a park where it dead ends. Not much flow occurs in this line most of the time.

Sampling Point 2 has an assortment of cast iron (C.I.) pipe, 8 and 12 inch (20 and 30 cm) plus a short section of 10 inch (25 cm) composing the 3 1/2 miles (6 km) of pipe to the Sample Point 2 from the treatment plant. The water passes through no A/C pipe before reaching Sample Point 2.

The absence of asbestos fibers in the samples taken from this system (Table 7) is because the water is non-aggressive as indicated by the Aggressive Index. Further, the low numbers of fibers from the cast-iron line demonstrates that in this situation, at least, the jointing materials are not a source of fibers. This pipe was not inspected.

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Table 7. Asbestos Fiber Counts for System E

| Date of Sample | Sample Point | | | | | |
|---|---|---|---|---|---|---|
| | Water Plant A.I. = 12.74 | | 1 A/C Pipe A.I. = x | | 2 C.I. Pipe A.I. = x | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL |
| 6/17/75 | BDL | BDL | BDL | NSS | BDL | NSS |
| 9/3/75 | BDL | BDL | BDL | 0.1 | BDL | NSS |
| 11/11/75 | BDL | BDL | BDL | BDL | BDL | BDL |
| 2/18/76 | BDL | BDL | BDL | BDL | BDL | BDL |
| 4/27/76 | BDL | NSS | BDL | NSS | BDL | BDL |

BDL (Below detection limits)

NSS (Not satistically significant)

MFL (Million fibers per liter)

x = Not Determined

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System F

System F has an average water use of 2 mgd (7,570 $m^3/d$) and serves a population of about 20,000. The water source is a man-made reservoir. Pretreatment given the water is aeration of the reservoir for taste and odor control purposes. The aeration provides an additional benefit by reducing the total hardness from about 130 mg/L to 96 mg/L as $CaCO_3$. The in-plant treatment consists of lime softening, ferric sulfate coagulant, polymer coagulant aid, sedimentation, filtration and disinfection with chlorine gas. The softened water leaves the plant with a total hardness of 40-48 mg/L as $CaCO_3$ and a turbidity of less than 0.1 ntu. The treated water has a pH of 9.7, a calcium hardness of 39 mg/L as $CaCO_3$ and an alkalinity of 36 mg/L as $CaCO_3$, resulting in an Aggressive Index of 12.85 (Table 1), which places it in the non-aggressive water category.

One of the distribution system Sampling Points (1) is located after 3 miles (5 km) of 12 in (30 cm) and 16 in (40 cm) A/C pipe. The pipe is Johns-Manville, Class 150, Type II installed in 1973. A few services are tapped off this line, but it serves mainly as a transmission line to an industrial user.

The other distribution system Sample Point (2) is located after 0.4 mile (0.6 km) of 12 in (30 cm) C.I. pipe. Possibly some water at this sample point could come through A/C pipe returning from a storage tank. The general absence of asbestos fibers (Table 8) in the samples taken from this system is because the water is non-aggressive as indicated by the Aggressive Index. As with system E, few fibers were present in water flowing through the cast-iron pipe. The A/C pipe was not inspected.

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Table 8. Asbestos Fiber Count from System F

| Date of Sample | Sample Point | | | | | |
|---|---|---|---|---|---|---|
| | Water Plant A.I. = 12.85 | | 1 A/C Pipe A.I. = x | | 2 C.I. Pipe A.I. =x | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphobile MFL | Chrysotile MFL |
| 6/26/75 | BDL | 0.2 | NSS | 0.3 | BDL | NSS |
| 9/4/75 | BDL | BDL | NSS | NSS | BDL | BDL |
| 11/18/75 | BDL | BDL | BDL | BDL | BDL | BDL |
| 2/18/76 | NSS | BDL | BDL | NSS | BDL | BDL |
| 4/26/76 | BDL | BDL | BDL | NSS | BDL | BDL |

BDL (Below detection limit)

NSS (Not statistically significant)

MFL (Million fibers per liter)

x = Not Determined

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System G

System G is a municipal water system using a surface water supply. The water is given conventional treatment followed by pH adjustment to 8.2 by addition of NaOH. The daily water use is about 7.5 mgd (28,400 $m^3/d$). The population served is 40,000. Table 1 places this water in the moderately aggressive category by virtue of its Aggressive Index 10.48.

Table 9 contains the asbestos fiber and water quality ranges found in system G. Sample Point 1 is after 6,000 ft (1.8 km) of A/C pipe while Sample Point 2 is after 13,300 ft (4.1 km) of A/C pipe, both Type II.

In Table 9 the increase in pH from the treatment plant to Sample Point 2 is greater than to Sample Point 1. The calcium concentrations also increase more over the longer run of A/C pipe to Sample Point 2. The calcium hydroxide or other calcium products in the cement binder are being dissolved and cause an increase in pH and calcium in the water. This again demonstrates that a water that is aggressive toward A/C pipe will continue to increase in pH and calcium with time of exposure, as the water seeks its calcium saturation level. Despite the loss of calcium by the A/C, inspection showed the pipe has not been softened although some pitting of the pipe has occurred.

The asbestos fiber data in Table 9 must be analyzed carefully to avoid misleading interpretation. The water leaving the treatment plant contained no asbestos fibers. This means that asbestos fibers found in the distribution system come from the pipe materials. The large fluctuation in the number of fibers found in various samples from both points in the distribution system from below detection limits to over 4 million fibers per liter indicates no severe general deterioration of the pipe. The higher fiber counts

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Table 9. Asbestos Fiber Counts for System G

| Date of Sample | Sample Point | | | | | |
|---|---|---|---|---|---|---|
| | Treatment Plant<br>pH 8.2 - 8.3<br>Ca 7-9 mg/L as $CaCO_3$<br>Alk. 20 mg/L as $CaCO_3$<br>A.I. 10.35-10.55 | | 1<br>pH 8.5 - 8.7<br>Ca 7-11 mg/L as $CaCO_3$<br>Alk. 24-35 mg/L as $CaCO_3$<br>A.I. 10.73-11.28 | | 2<br>pH 8.7 - 9.2<br>Ca 10-17 mg/L as $CaCO_3$<br>Alk 7-11 mg/L as $CaCO_3$<br>A.I. 10.55 - 11.47 | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL |
| 3/2/76 | BDL | BDL | NSS | 0.2 | x | x |
| 10/17/77 | x | x | BDL | 1.1 | x | x |
| 11/2/77* | x | x | BDL | 0.1 | BDL | 0.2 |
| 1/20/78 | x | x | BDL | 4.6 | BDL | 0.1 |
| 3/17/78 | x | x | BDL | NSS | BDL | BDL |
| 4/28/78 | x | x | NSS | NSS | BDL | BDL |
| 6/2/78 | x | x | NSS | 2.5 | NSS | 3.1 |
| 8/1/78 | x | x | NSS | 4.0 | BDL | NSS |
| 9/22/78 | x | x | NSS | 1.1 | NSS | 1.8 |
| 11/17/78 | x | x | BDL | 1.0 | NSS | NSS |

BDL (Below detection limits)

NSS (Not statistically significant)

MFL (Million fibers per liter)

x = Not determined

* - Control Measures Started - See Text

ST0055593

occurred after tapping of A/C pipe in the sample collection area. Therefore, asbestos fiber counts from individual samples do not always provide a true indication of A/C pipe condition.

Note, the DWRD has a research grant with this utility to study methods of reducing fiber loss from the A/C pipe by adding zinc orthophosphate to the water. This study is underway, but results are not available at this time (Spring 1979).

System H

System H is a privately owned water system with a well water source. The daily water use for system H is 0.1 mgd (380 $m^3/d$) and the population served is 1,200. This water has high iron content and a zeolite water softener was installed to remove the iron. The softener also removed the calcium from the water and created a very aggressive water (Table 1). Table 10 contains the water quality data and the asbestos fiber counts for System H.

Water from Sample Point 1 had gone through about 5000 ft (1530 m) of A/C pipe; water from Sample Point 2 had gone through about 6000 ft (1830 m) of a combination of A/C and PVC pipe; and water from Sample Point 3 had gone through about 11,000 ft (3350 m) of A/C pipe, all Type II.

ST0005594

Table 10. Asbestos Fiber Counts for System H

| Date of Sample | Sample Points | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Treatment Plant<br>pH 7.1<br>Ca 0.5 mg/L as $CaCO_3$<br>Alk. 89 mg/L as $CaCO_3$<br>A.I. = 8.74 | | 1<br>pH 7.2<br>Ca 2.0 mg/L as $CaCO_3$<br>Alk.92 mg/L as $CaCO_3$<br>A.I. = 9.46 | | 2<br>A.I. = x | | 3<br>A.I. = x | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amph. MFL | Chry. MFL | Amph. MFL | Chry. MFL |
| 9/15/76 | BDL | BDL | 0.7 | 19 | x | x | x | x |
| 10/12/78 | x | x | x | x | BDL | 4.2 | NSS | 5.7 |

BDL (Below detection limits)

NSS (Not statistically significant)

MFL (Million fibers per liter)

x - Not Determined



ST0005595

Despite the apparently small change in pH and calcium between the treatment plant and Sample Point 1 (only one mile, 1500 m) the asbestos fibers counts in the water were quite high. Water quality data from Sample Points 2 and 3, if measured, might have shown increases more typical of an aggressive system. The Aggressive Index of 8.74 classes this water as very aggressive. The high fiber counts showing at all sample points indicates that the asbestos-cement pipe is being attacked. Inspection of the pipe showed that the cement binder has been dissolved to the depth of about 1/8 inch (0.3 cm).

Note, the DWRD has a research contract with this utility to attempt to rehabilitate the pipe after cleaning using the McCauley processes[4,5]. Rehabilitation has not yet started (Spring 1979).

System I

System I is a municipal water supply with two surface and three well sources for its water. All of the waters are soft with low alkalinity. The water quality ranges for the source waters are pH 6.4 - 6.6 alkalinity from 4 to 23 mg/L as $CaCO_3$ and calcium concentrations from 2 to 14 mg/L as $CaCO_3$ . The only treatment provided is chlorination, which at times depresses the pH to less than 5. Water use is about 3 mgd (11,300 $m^3/d$) serving a population of about 25,000. The distribution system contains about 54 mi (87 km) of Type II A/C pipe and 50 mi (81 km) of cast iron pipe. Sample Point 1 is after 13,250 ft (4040 m) of A/C pipe and Sample Point 2 is after 5800 ft (1770 m) of A/C pipe. Sample Point 3 is a deadend situation after 9,350 ft (2820 m) of A/C pipe.

ST0005596

Table 11. Asbestos Fiber Counts for System I

| Date of Sample | Sample Points | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Comb. Sources After $Cl_2$ pH 4.5-6.0 Ca 5.8-7.5 mg/L as $CaCO_3$ Alk. 4.0 mg/L as $CaCO_3$ A.I. 6.0-7.5 | | 1 pH 4.7-6.0 Ca 4.8-6.0 mg/L as $CaCO_3$ Alk. 1-2 mg/L as $CaCO_3$ A.I. = 5.38-7.08 | | 2 pH 6.0 Ca 7.5 mg/L as $CaCO_3$ Alk. 4.0 mg/L as $CaCO_3$ A.I. = 7.46 | | 3 pH 9.0 Ca 22.5 mg/L as $CaCO_3$ Alk. 18 mg/L as $CaCO_3$ A.I. = 11.61 Deadend | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MLF |
| 6/25/75 | BDL | NSS | BDL | 0.1 | x | x | x | x |
| 9/12/75 | x | x | BDL | 0.2 | x | x | x | x |
| 6/30/76 | x | x | BDL | 0.1 | x | x | x | x |
| 7/28/76 | x | x | x | x | NSS | NSS | 9.6 | 190 |

BDL (Below detection limit)

NSS (Not statistically significant)

MFL (Million fibers per liter)

x = Not determined



ST0095507

The data from System I proved to be quite puzzling but informative. The water entering the distribution system had an Agressive Index ranging from 6.0 to 7.5 which is a severely aggressive water. Very high asbestos fiber counts were expected in all the water samples. Table 11 shows that this was not true at Sample Point 1 and 2. Also the pH had not increased significantly at Sample Points 1 and 2. The sample at Sample Point 3 showed a large pH increase and very high asbestos fiber counts that would indicate A/C pipe deterioration.

A/C pipe sections were removed from the system to locate the deteriorated areas. None of the pipe showed any signs of deterioration except for a slight softening of the surface. No visible asbestos fibers were showing, however. The pipe section from the deadend sample, Sample Point 3, had markings along the sides indicating that 2-3 inches (5-8 cm) of debris had collected in the bottom. Because the pipe had not deteriorated, the high asbestos fiber counts must have come from stirring up of this debris that was probably collected from pipe tappings.

All of the excavated A/C pipe was coated with an iron rust - appearing substance that apparently protected the pipe from deterioration. The iron content in the water was between 0.1 and 0.15 mg/L. Whether or not the iron alone is responsible for the protection of the pipe, is not known at this time (Spring, 1979). Protection of A/C pipe by an iron rust-like coating has been experienced in laboratory experiments (discussed later in the paper) and by others discussing existing systems with the authors. Efforts are being made to identify the reactions in this protective phenomenon, (Research Grant No. R-805638, Zajicek, Univ. of Massachuetts, Principal Investigator). Results are not available at this time (Spring 1979).

Identifying the very high asbestos fiber counts at Sample Point

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3 as being related to drilling and tapping of the A/C pipe and not general pipe deterioration suggests increased caution regarding evaluation of A/C pipe condition only by examination of a single water sample for asbestos fiber content.

System J

System J is a municipal well water supply of 0.6 mgd (2270 $m^3/d$) that serves a population of 3,500. System J Samples Points 1, 2 and 3 are located after 3,035 ft (925 m), 6,780 ft (2070 m), 5,980 ft (1825 m) of Type II A/C pipe respectively. Table 12 contains the asbestos fiber count data. The A/C pipe that was removed from System J had been attacked and the cement binding compound had been dissolved to a depth of about 1/8 inch (0.3 cm) in 5 years. This is to be expected from a calcium starved water that would attack almost all piping materials in general use for drinking water transportation.

In-House Research

A/C Pipe Experimental Pipe Loop

In late 1973 the USEPA Drinking Water Research Division was given the assignment to investigate the performance of A/C pipe when exposed to a variety of water conditions. Advisors knowledgeable in the performance of A/C pipe at that time suggested that no small laboratory scale experiments would be acceptable for A/C pipe studies. DWRD proceeded, therefore, to put a recirculating experimental pipe loop into operation using several full lengths of 4 in (10 cm) and 6 in (15 cm) diameter A/C pipe. The pipe loop experiment was started in late 1974 and operated until mid-1977.

Although these experiments were not considered successful, the pipe loop produced a few worthwhile findings. The most important of these were:

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Table 12. Asbestos Fiber Counts for System J

| Date of Sample | Sample Points | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Well Source A.I.= 5.67 | | 1 A.I. = x | | 2 A.I. = x | | 3 A.I. =x | |
| | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amphibole MFL | Chrysotile MFL | Amph. MFL | Chry. MFL |
| 6/20/78 | NSS | 0.8 | BDL | 550 | NSS | 380 | x | x |
| 10/25/78 | x | x | x | x | x | x | NSS | 120 |

BDL (Below detection limit)

NSS (Not statistically significant)

MFL (Million fibers per liter)

x = Not determined



S1000560

1. That iron dissolved in the water would precipitate to provide a protective coating to the A/C pipe even under highly aggressive water quality conditions. For example, a water with pH 5.5, a calcium concentration of 10-15 mg/L as $CaCO_3$ and a total alkalinity of 1-3 mg/L as $CaCO_3$, initially showed signs of being aggressive to the A/C pipe by leaching calcium from the pipe early in the experimental run. Later, iron, dissolved from some of the experimental equipment, combined chemically in some way with the pipe wall to provide a protective coating on the A/C pipe. This halted the leaching of the calcium.

2. That under the pipe loop experimental conditions waters with moderately aggressive Aggressive Indices did attack autoclaved A/C pipe even though this was not predicted. The attack on the A/C pipe during these moderately aggressive experimental conditions was, however, exaggerated when compared to actual water system conditions. In tests with Aggressive Indices of both 10.4 and 11.7 the A/C pipe was softened. The Aggressive Index 10.4 test resulted in much more severe attack than the 11.7 test, however.

During both of these experiments the water was not saturated for calcium carbonate and it was maintained in an unstable condition through pH, alkalinity and calcium adjustments. The Aggressive Index 11.7 conditions were achieved by maintaining a pH of 7.5, a calcium concentration of 150 mg/L as $CaCO_3$ and an alkalinity of 100 mg/L as $CaCO_3$. Continual feed of sodium bicarbonate to maintain the desired alkalinity was opposed by continuous feed of HCl to maintain the pH at 7.5. The difficulties encountered in maintaining pH and alkalinity at

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desired concentrations were the re · lt of operating a system in which the water was in contact with the carbon dioxide in the atmosphere in an open reservoir.

Softening of the A/C pipe has been observed in A/C pipe installations with moderately low Aggressive Indices, but not as severe as occurred under the pipe loop conditions. This demonstrated the importance of stable water conditions when evaluating A/C pipe performance and the importance of sealed laboratory A/C pipe or other corrosion experiments. The unsealed pipe loop was not representative of field conditions

3. The pipe drillings and tapping operations can greatly influence asbestos fiber counts in water. During the A/C pipe loop experiments the pipe was drilled and tapped under pressure with water flowing through the pipe. The first tapping experiment was done using a standard pipe tapping machine with no chip flushing arrangement. Tapping caused the asbestos fiber counts to increase greatly and two weeks passed before the fiber counts returned to "before tapping" levels in spite of filtration for removal of all of the fibers with each pass of recirculating water.

In a later experiment A/C pipe was tapped under the same conditions except that the tapping machine had been modified by installation of a flushing valve to flush out A/C pipe chips and debris created during the drilling and tapping operations. In this case, the asbestos fiber counts increased during tapping, but returned to "before tapping" levels by the next day.

The flushing valve was wide open throughout the drilling and tapping operation. Considerable debris was collected from the flushing stream. The flushing valve must be fully open during drilling and

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tapping because without a strong continuous flow much of the debris will fall into the pipe.

Many regular pressure tapping machines can be modified by adding a flushing valve by the use of a commercially available kit. New tapping machines can now be purchased with a flushing valve.

A/C Coupon Tests

General Description

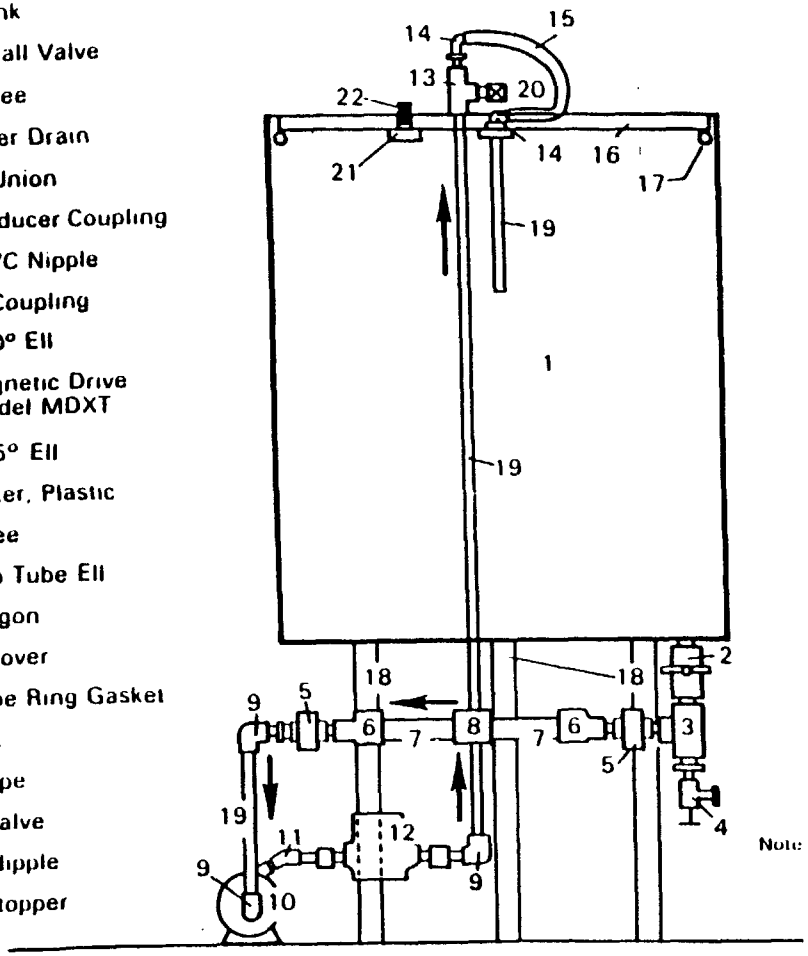
The unsatisfactory performance of the full scale A/C pipe experiments led to the conclusion that small scale, better controlled testing should be tried, despite the belief that small scale work might be misleading. Figure 1 shows the small scale experimental setup with the important parts identified. Anyone desiring more detailed information regarding this equipment should contact the authors of this paper.

The A/C pipe used in this type of experiment is a coupon cut from Class 150, Type II, 4 in. (10 cm) pipe. The coupon is 6 in. (15 cm) long and of a width that will have a close fit inside a 1-1/2 in (4 cm) PVC pipe, part No. 7 on Figure 1, see Figure 2. The edges are sealed.

This experimental arrangement was designed to allow ease in operation and extended use of recirculated water between changes. The 100 gal. (380 L) volume of the recirculation water reacting on a small piece of A/C pipe satisfied this objective. The water is recirculated continuously through the PVC pipe that holds the A/C coupon. The water flow rate is 3 gpm (11 L/min) providing a velocity of about 1 foot per second (FPS) (0.35 MPS) past the coupon, a reasonable flow.

ST0095603

| Part No | Description |
|---|---|
| *1 | 100 gal. Tank |
| 2 | 1" Plastic Ball Valve |
| 3 | 1" Plastic Tee |
| 4 | Plastic Boiler Drain |
| 5 | 1" Plastic Union |
| 6 | 1½"x1" Reducer Coupling |
| **7 | 1½"x6" PVC Nipple |
| 8 | 1½" PVC Coupling |
| 9 | ½" PVC 90° Ell |
| 10 | Pump-Magnetic Drive March Model MDXT |
| 11 | ½" PVC 45° Ell |
| 12 | Water Meter, Plastic |
| 13 | ½" PVC Tee |
| 14 | ½" Pipe to Tube Ell |
| 15 | ½" I.D. Tygon |
| ***16 | Floating Cover |
| 17 | Tygon Tube Ring Gasket |
| 18 | Tank Legs |
| 19 | ½"PVC Pipe |
| 20 | Sample Valve |
| 21 | ¾" PVC Nipple |
| 22 | Rubber Stopper |




* 100 gal. tank can be stainless steel or plastic

** Part #7 serves as the A. C. pipe coupon holder

*** Floating cover made from ⅛" sheet PVC. 1" strip of PVC cemented around edge of disc to form floating pan. Threaded fittings in cover require build up of PVC

Note: Pipe bushings and nipples required to make connections are not numbered and described

# Asbestos-Cement Pipe Small Scale Corrosion Experimental Set Up

Figure 1.

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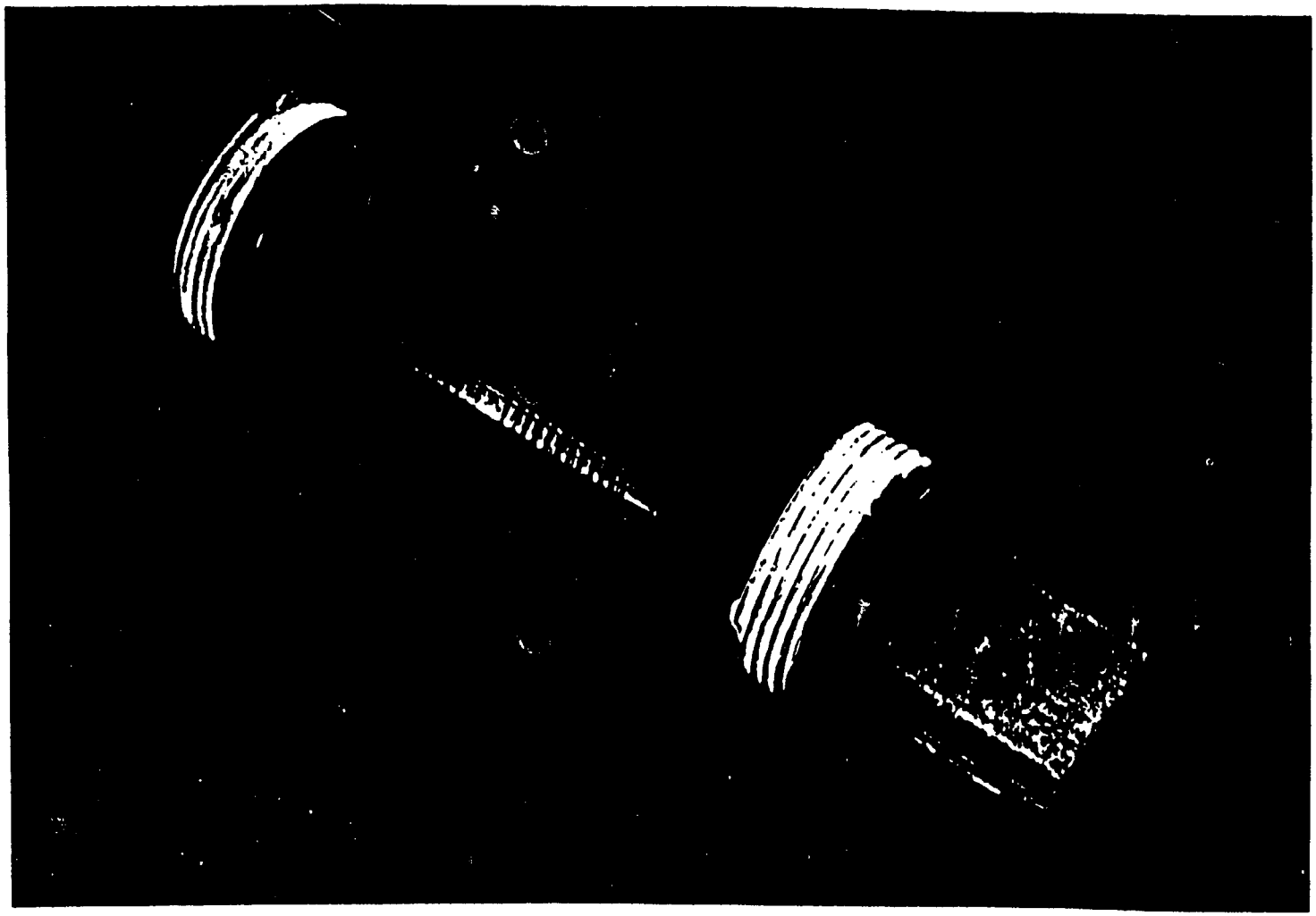

FIGURE 2 PHOTOGRAPH OF A/C PIPE COUPON IN HOLDER

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General Water Quality Control

The water quality constituents that were controlled and monitored were few. They were concentrations of calcium, alkalinity, free residual chlorine and pH. The temperature and total dissolved solids (TDS) concentrations were also measured but not controlled. Concentration of dissolved oxygen (D.O.) and carbon dioxide ($CO_2$) were measured during the early experiments. The concentration of $CO_2$ was found to be insigificant and the concentration of D.O. was always relatively high (6-8 mg/L) so they were only measured occasionally. The desired calcium concentration was achieved by diluting Cincinnati tap water with deioniozed water. Alkalinity was adjusted by the addition of sodium bicarbonate. The pH was regulated by the addition of sodium hydroxide or hydrochloric acid. The free chlorine residual concentration was maintained at a minimum of 0.2 mg/L by use of a chlorine solution made from chlorine gas (calcium hypochlorite would have added calcium).

Development of Testing Protocol

Because of the pipe loop experience, the problems caused by exposure of the water to atmospheric $CO_2$ were known, but with a continuous automatic water quality adjustment arrangement such as used with the pipe loop experiments, the severity of the $CO_2$ effects were not fully realized. The first small scale experiments used a loosely covered reservoir (Part 1, Figure 1) to keep out dust and reduce evapoation. During these first experiments pH's of 7.0 and 8.2 were established to investigate possible trends. Low calcium and alkalinity concentrations, 3-10 mg/L calcium as $CaCO_3$ and a total alkalinity of 20 mg/L as $CaCO_3$ were used. These experiments were mainly for procedural development so they will be generally discussed. After acceptable operational procedures were developed these early experiments were repeated under

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better controlled conditions and detailed results will be given in the next section of this paper.

The water in the"loosely covered reservoir" experiments performed at pH 8.2 experienced a continuous gradual increase in alkalinity. pH also required daily adjustment because the pH would drop almost 0.2 units each day. The water in the experiment at pH 7.0 experienced a daily increase of 0.2-0.3 pH units plus a continuous decline in alkalinity, requiring daily correction and attention.

Despite the water quality control problems experienced in this set of experiments they indicated how the A/C pipe coupon might behave. The water in the pH 7.0 tests was more aggressive toward the A/C pipe coupon than the water in the pH 8.2 tests,as indicated by surface softening.

The difficulty in controlling water quality using loosely covered reservoirs led to some small bench top sealed experiments that demonstrated that pH drift could be eliminated by sealing from the atmosphere. Therefore, floating covers were installed on the recirculation tanks to make them essentially sealed systems. Not only did this help maintain water quality but also a sealed system would be more representative of a water distribution network than one with atmospheric exposure.

When using a sealed system, however, precautions must be taken when making pH determinations. The pH of water taken from a sealed system can easily vary 0.2 to 0.6 pH units from the actual pH if the pH is measured using a pH meter with the sample exposed to the atmosphere. This type of pH variation or drift occurs with many well waters, but usually goes unnoticed and accounts for many inaccurate pH readings. A method of determining accurate pH values using sealed conditions that eliminates pH drift has been developed and can be obtained by contacting the authors of this paper.

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Use of the sealed systems reduced the pH adjustment needed for a pH 8.2 system to once a week and this adjustment was mainly to counteract the effect of weekly chlorination. The pH 7.0 sealed systems rarely required any pH adjustment compared to the daily need in the loosely covered systems. The alkalinity in both pH 7.0 and 8.2 systems never required adjustment through an entire experimental run of 6 to 8 months. Although the water quality does change during a test because of recirculation, the changes are slight. Tests where the water was changed in mid-run showed that the rate of calcium dissolution was the same after the change of water as just before it was changed. Therefore, the results seem applicable to a "once through" system. A standardized testing protocol was thus established.

Description of Experiments and Results

Table 13 lists the well controlled experiments that have been completed to date (Spring 1979).

Table 13. Water Quality Conditions for Small Scale Experiments

| Experiment No. | pH | Calcium mg/L as $CaCO_3$ | Total Alkal. mg/L as $CaCO_3$ | Aggressive Index | Corrosion Control Method |
|---|---|---|---|---|---|
| 1 | 8.2 | 6 | 20 | 10.28 | None |
| 2 | 8.2 | 6 | 20 | 10.28 | Zinc Orthophosphate |
| 3 | 7.0 | 10 | 20 | 9.30 | None |
| 4 | 7.0 | 10 | 20 | 9.30 | Zinc Orthophosphate |
| 5 | 8.2 | 6 | 20 | 10.28 | Zinc Chloride |
| 6 | 7.5 | 145 | 125 | 11.76 | None |
| 7 | 7.9 | 145 | 125 | 12.16 | Slightly positive Langlier Index* |
| 8 | 9.0 | 25 | 40 | 12.00 | $CaCO_3$ Saturation |

*Langlier Index = pH - $pH_s$ (6)
where $pH_s$ = pH at calcium carbonate saturation

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In some experiments zinc compounds were tested as a possible protection for A/C pipe. The observation or iron and manganese compunds coating and protecting A/C pipe both in the field and the pipe loop raised the possibility that zinc might act in the same manner. Both iron and manganese have demonstrated protection potential, but they are undesirable as an additive to finished drinking water. Zinc is not undesirable in low concentrations in drinking water and is used in corrosion control compounds for metal pipes. The effect of zinc on industrial processes would have to be determined, however. The reason for using the very low calcium and alkalinity concentrations in experiments 1 through 5 was to imitate the water quality existing at an EPA research grant site on A/C pipe, system G, in the field studies.

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Experiment 1 (pH 8.2, Ca 6 mg/L as $CaCO_3$, Alk. 20 mg/l as $CaCO_3$, A.I. 10.28)

During 6 months of operation the alkalinity had increased from 20 to 26 mg/L as $CaCO_3$ in the water. The calcium concentration had also increased from 5.3 to 13.5 mg/L as $CaCO_3$ during this period indicating that some dissolution of the A/C pipe had occurred. Examination of the coupon confirmed this assumption because the inner pipe surface was softened and could be gouged with a fingernail. Note: Although the flowing water contacts both the inside and outside of the A/C coupon and this might influence the absolute magnitude of the changes in the concentrations of calcium and alkalinity, the result of the experiment is judged from the examination of the condition of only the inner wall of the coupon.

Experiment 2 (pH 8.2, Ca 6 mg/L as $CaCO_3$, Alk. 20 mg/L as $CaCO_3$, A.I. 10.28, Zinc Orthophosphate)

Experiment 2 differs from 1 only in that zinc orthophosphate was

added to produce a zinc concentration of 0.3 to 0.5 mg/L. The alkalinity in the recirculated water increased from 20 to 25 mg/L as $CaCO_3$ and the calcium concentration from 5.0 to 6.1 mg/L as $CaCO_3$ in 6 months. Mah and Boatman [7] also reported no apparent loss of calcium by A/C pipe during experiments using zinc orthophosphate. The small calcium increase in the water was indicative of little or no attack on the A/C pipe. Examination showed that the coupon had retained its hard, smooth inner surface condition. A light gray coating was on the pipe surface that could be scratched through to the darker gray color of unused A/C pipe. The A/C pipe appears to be well protected by the zinc in the water.

Experiment 3 (pH 7.0, Ca 10 mg/L as $CaCO_3$, Alk. 20 mg/L as $CaCO_3$, A.I. 9.3)

During 6 months of operation with lower pH water, the alkalinity in the recirculation water increased from 20 to 23 mg/L as $CaCO_3$ and the calcium concentration increased from 10 to 20 mg/L as $CaCO_3$. The calcium increase predicted dissolution of the cement from the coupon and this was confirmed by the softening of the pipe as determined during the final examination.

Experiment 4 (pH 7.0, Ca 10 mg/L as $CaCO_3$, Alk. 20 mg/L as $CaCO_3$, A.I. 9.3, Zinc orthophosphate)

Experiment 4 differs from 3 only in the use of zinc orthophosphate. During 6 months the alkalinity in the water increased from 20 to 29 mg/L as $CaCO_3$ and the calcium concentration from 10 to 17 mg/L as $CaCO_3$. The calcium increase was almost as great as in experiment 3 where no zinc orthophosphate was used. Inspection revealed that the A/C pipe coupon was softened somewhat as expected from the calcium data. It was, however, in better condition than in either the pH 7.0 and pH 8.2 experiments with no zinc present.

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Experiments 1 through 4 clearly established that the pH must be higher if the zinc was to protect the pipe. The order of performance from best to worst was: pH 8.2 plus zinc; pH 7.0 plus zinc; pH 8.2 and pH 7.0.

Experiment 5 (pH 8.2, Ca 6 mg/L as $CaCO_3$, Alk. 20 mg/L as $CaCO_3$, A.I. 10.28, Zinc chloride)

During the zinc orthophosphate experiment the zinc was depleted gradually, but the phosphate was not. This indicated that the protection provided might be related to the zinc alone and not the form of the zinc compound being used. In discussing this with O.T. Zajicek, Assoc. Professor of Chemistry, University of Massachusetts, he suggested the use of zinc chloride as a source for the zinc.

Experiment 5, therefore, was a repeat of experiment 2 with zinc chloride being substituted for zinc orthophosphate. The operation and results of the two experiments were practically identical. A slight increase in the calcium concentration occurred during the first 3 weeks of the 6 month test, but none thereafter. The zinc concentration also declined more early in the study when it was reduced from a concentration of 0.7 mg/L to 0.4 mg/L in 3 weeks. During the latter part of this experiment, the zinc decreased by this same amount in 21 weeks. The possibility of some early conditioning of the system exists.

This experiment showed that zinc in various compounds could be used to protect A/C pipe. The A/C coupon at the end of this test was clean and hard with a light gray colored film on the surface.

Experiments 6 & 7 (pH 7.5 (6) and 7.9 (7), Ca 145 mg/L as $CaCO_3$ Alk. 125 as $CaCO_3$, A.I. 11.76(6) and 12.16 (7))

Experiments 6 and 7 were companion tests to demonstrate the performance of $CaCO_3$ as a protection mechanism under conditions of saturation and unsaturation with pH being the variable to control the $CaCO_3$ saturation. According to Caldwell-

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Lawrence diagrams [8], a water such as used in these experiments would be saturated for $CaCO_3$ at a pH of about 7.75 ($pH_s$) with a calcium concentration of 145 mg/L as $CaCO_3$ an alkalinity of 125 mg/L as $CaCO_3$, a temperature of 23.5°C and TDS of 350 mg/L. Therefore, experiment 6 at pH 7.5 was operated with a slightly negative Langlier Index and experiment 7 at pH 7.9 had a slightly positive Langlier Index.

At the end of 31 weeks, inspection showed that the A/C coupon in the pH 7.5 water was softened and appeared to have acquired a light coating. On the other hand, inspection showed that the A/C coupon in the pH 7.9 system remained hard and clean. The slight change in pH from below $pH_s$ at pH 7.5 to above $pH_s$ at pH 7.9 is equivalent to about 40 mg/L calcium as $CaCO_3$ if calcium rather than pH was the parameter used to alter conditions. Experiment 6 demonstrates that an unstabilized water with respect to $CaCO_3$ will attack A/C pipe despite a high Aggressive Index of 11.76. This exaggerated situation would most likely never occur naturally, but does point out that placing absolute confidence in a single water quality standard for all waters is not reasonable.

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Experiment 8 (pH 9.0, Ca 25 mg/L as $CaCO_3$, Alk. 40 mg/L as $CaCO_3$, A.I. 12.00, at $pH_s$)

Experiment 8 tested a water at $CaCO_3$ saturation[8]. Inspection of the inner wall of the coupon from this test showed it to be very slightly softened after 31 weeks. When compared to experiments 6 and 7 this coupon was between them with respect to the hardness of the inside wall of the A/C pipe coupon.

These tests will continue, testing other water quality parameters and corrosion protection techniques. A mechanical device will also be used to help compare the final condition of the inner pipe wall.

## DISCUSSION

### Field Evaluation Studies

A field evaluation was made of ten water utilities having various water qualities and using A/C pipe. Samples of water before it entered the pipe and after flowing through A/C pipe were examined under an electron microscope to determine the possible release of asbestos fibers from the pipe walls. The combinations of pH, alkalinity, and calcium hardness in these ten utilities produced Aggressive Indices (A.I.), as defined by AWWA Standard (C400-77[1] from 5.34 to 12.85 with five being below 10.0, two between 10.0 and 12.0, and three above 12.0 as the water entered the distribution system. Of the three above an Aggressive Index of 12.0 one had a moderate pH (7.8) but high alkalinity and calcium hardness, while the other two had higher pH's 9.4 and 9.7, but lower values for the other two factors in the Index. A reasonable spread of water quality factors was covered (see Table 1).

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### Asbestos Fiber Counts and Pipe Conditions

Consistently quantifiable asbestos fiber counts were found in four of the five systems with an Aggressive Index below 10.0 and in one of the systems with an Aggressive Index above 10.0, (See Table 14). The three systems with an Aggressive Index over 12 and the one with an Aggressive Index of 11.56 showed no asbestos fibers or very inconsistent fibers regardless of the combinations of pH, alkalinity and calcium hardness. Inspection of the pipe from the one system, I, with an Aggressive Index below 10 (7.46) that did not have consistent asbestos fiber counts showed that a protective iron rustlike coating existed on the A/C pipe. This type of behavior will be discussed more later.

Table 14. SUMMARY OF DATA COLLECTED

| System | Initial Aggressive Index | pH | Alkalinity mg/L as $CaCO_3$ | Calcium Hardness mg/L as $CaCO_3$ | Consistently Quantifiable Fibers | Pipe Wall Deteriorated as Determined by Inspection | |
|---|---|---|---|---|---|---|---|
| A | 5.34 | 5.2 | 1.0 | 1.4 | Yes | Yes | |
| J | 5.67 | 4.8 | 3.0 | 2.5 | Yes | Yes | Figure 3 |
| I | 7.46 | 6.0 | 4.0 | 7.5 | No | No | Figure 4 |
| H | 8.74 | 7.1 | 89 | 0.5 | Yes | Yes | Figure 5 |
| B | 9.51 | 7.2 | 14 | 14.5 | Yes | Yes | Figure 6 |
| G | 10.48 | 8.3 | 20 | 7.5 | Yes | N.I. | |
| C | 11.56 | 7.5 | 88 | 82 | No | N.I. | |
| D | 12.54 | 7.8 | 220 | 250 | No | N.I. | |
| E | 12.74 | 9.4 | 50 | 44 | No | N.I. | |

N.I. = Not Inspected

Although in this study pipe from systems with a higher Aggressive Index was not inspected, inspection of a piece of pipe 30 years old from a system with the following water quality, pH 7.2, calcium concentration 124 mg/L as $CaCO_3$, alkalinity 75 mg/L as $CaCO_3$, Aggressive Index 11.2, showed the pipe wall to be sound and hard./ Figure 7. The pH at calcium carbonate saturation ($pH_s$) for a water with these calcium and alkalinity concentrations is higher than 8.0. Yet this water has provided a very smooth lining inside of the pipe at pH 7.2. Examination of the water quality data gives no hint as to what helps create and maintain this excellent interior pipe surface. Elements that are known to coat and protect the pipe are not visually detected through the color of the coating. The rust color from iron, the black color from manganese, or the gray color from zinc do not stand out. The concentration of these elements in the water were 0.05 mg/L iron,

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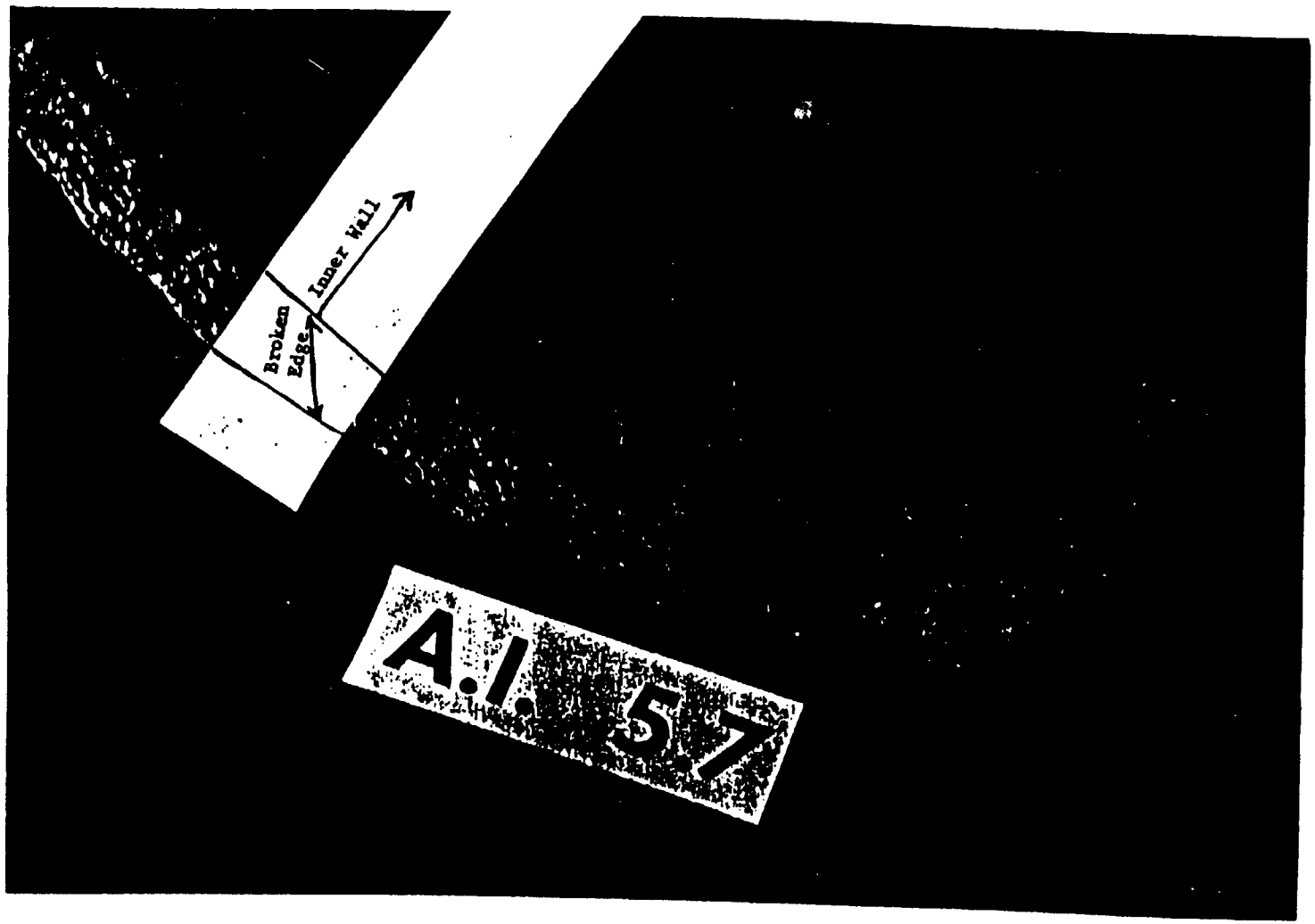


FIGURE 3 SYSTEM J

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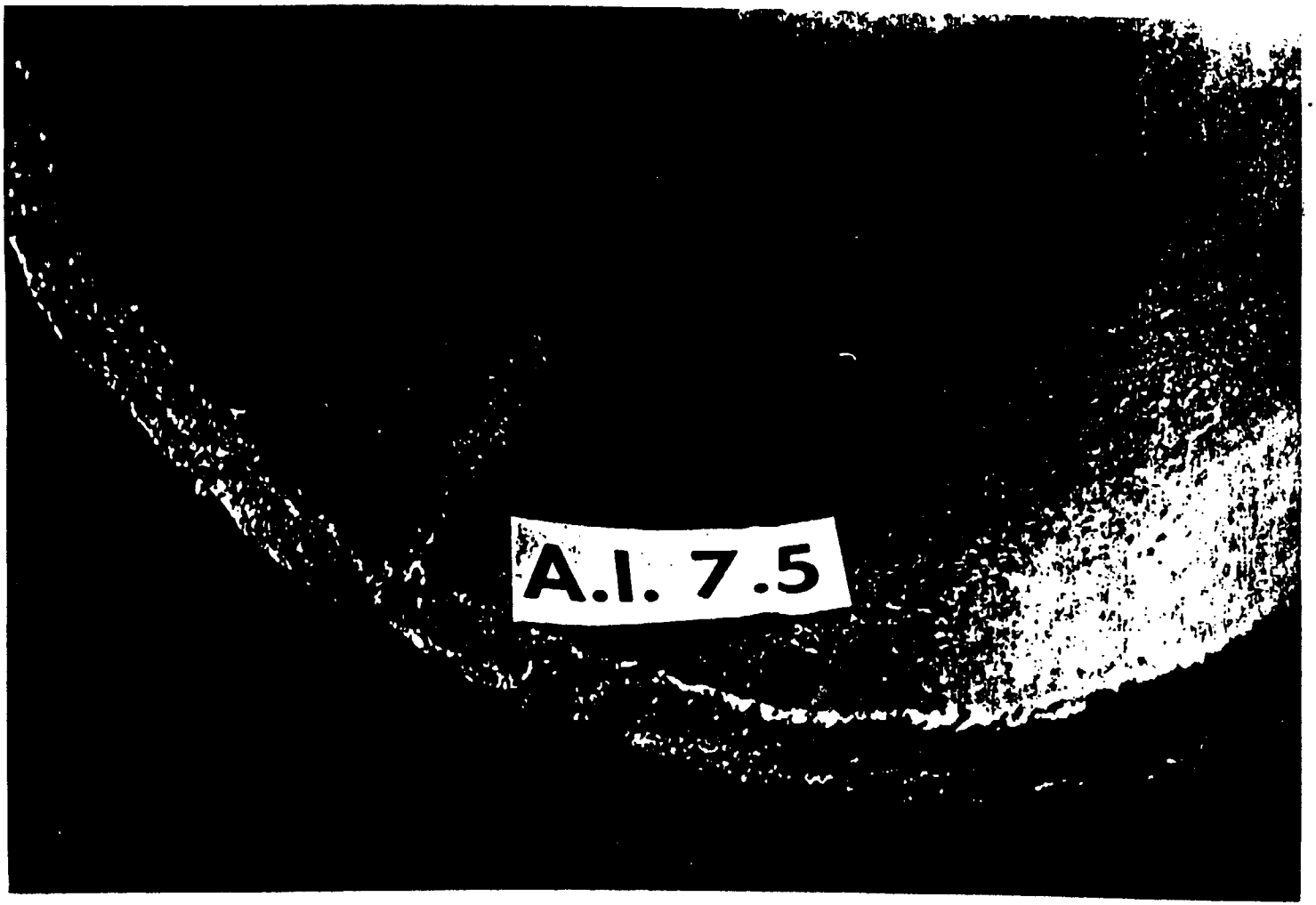


FIGURE 4 SYSTEM I

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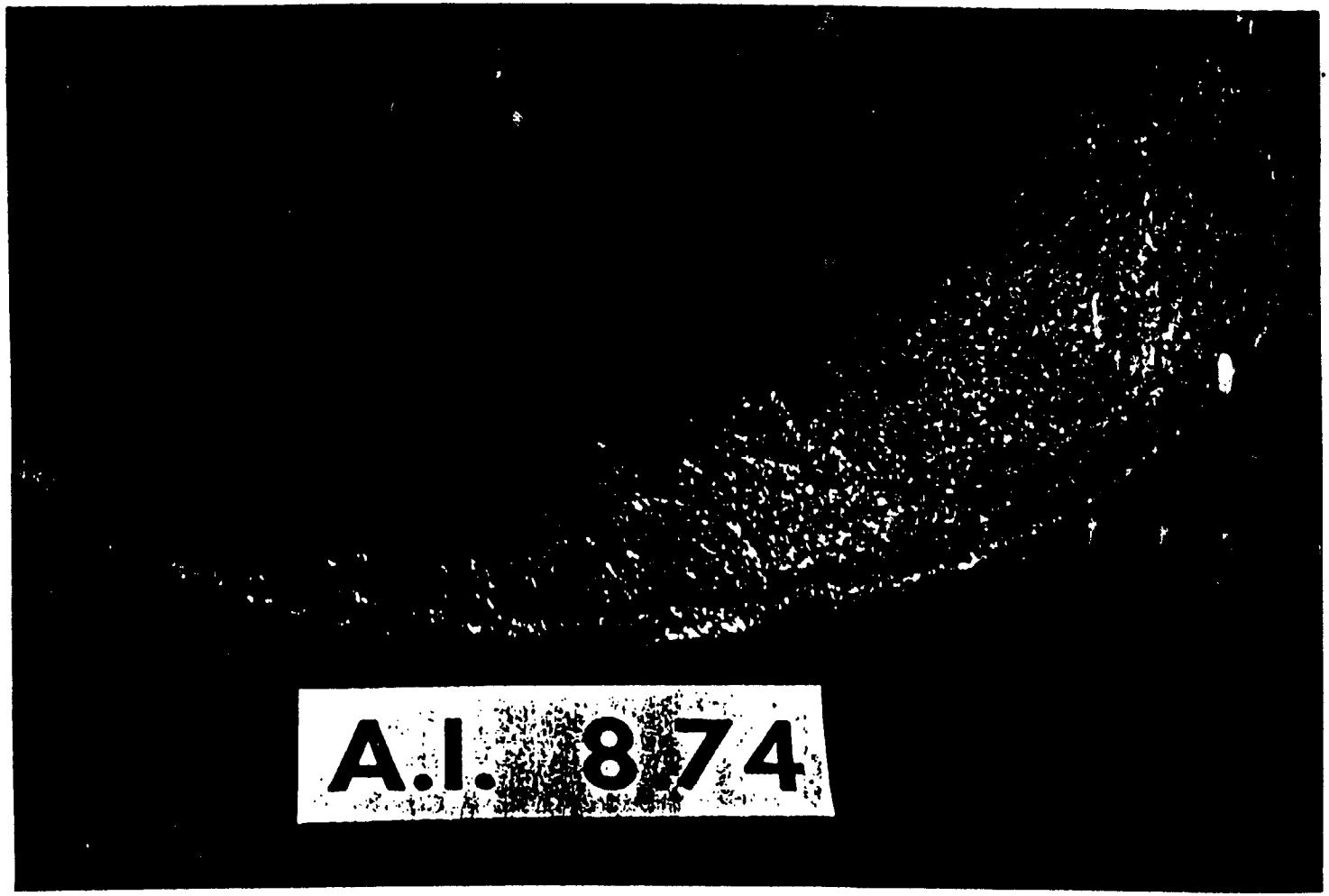


FIGURE 5 SYSTEM H

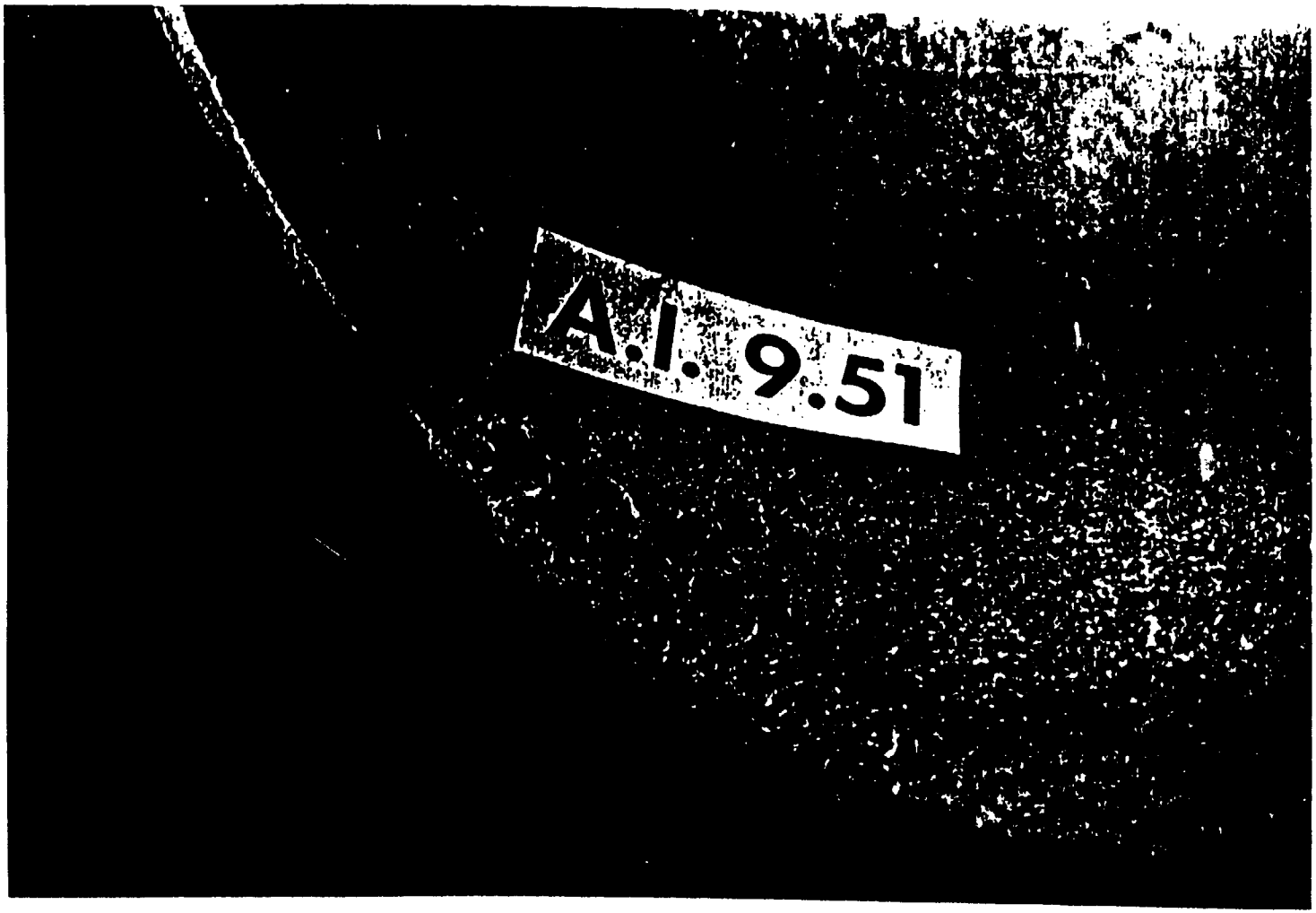


FIGURE 6 SYSTEM B

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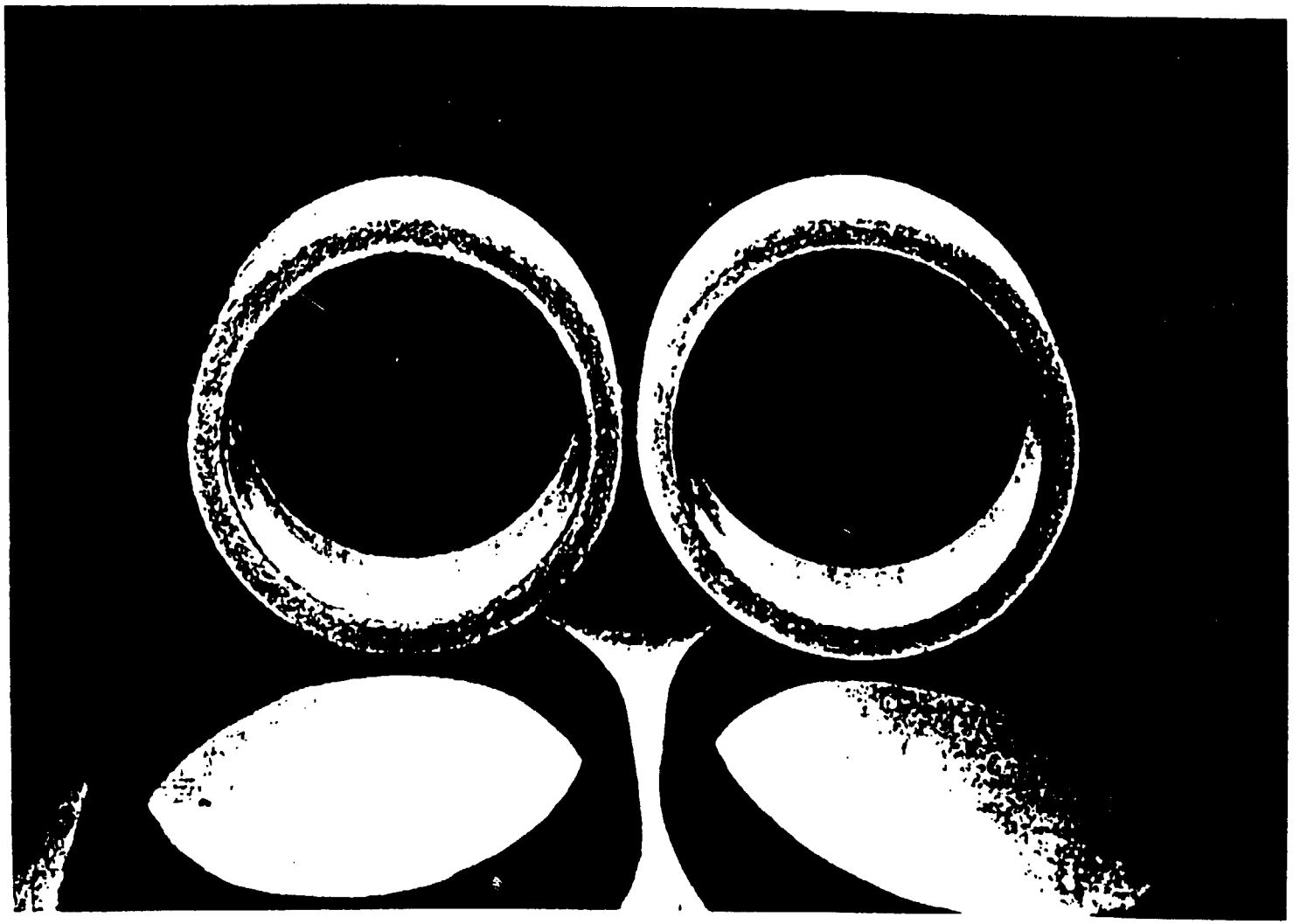

FIGURE 7 NEW 30 YEARS OLD

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0.004 mg/L manganese, and zinc 0.01 mg/L. These concentrations are quite low, but protection by iron compounds at slightly over 0.1 mg/L iron was reported earlier, System I. Further investigation of the effect, if any, of low levels of these apparently protective materials is needed.

Patterns of Pipe Attack

When an aggressive ... sses through A/C pipe, the pH and calcium content ... gressive Index to increase) because of the wa... e cement out of the pipe. This is well demonstrated by the ... f these factors in the water in System B between the source and ... ple Points 1 and 2. This change then caused the Aggressive Index to increase from 9.51 at the source to 10.17 at Sample Point 1 to 11.78 at Sample Point 2 (Table 3). The much greater length of A/C pipe between Sample Point 1 and Sample Point 2 than between the source and Sample Point 1 provided the larger increase in Aggressive Index (1.61 units vs. 0.66 units) even though the rate of Aggressive Index increase will slow as a stabilized water condition is approached in a given segment of a distribution system.

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System A demonstrates this same condition between the source and its Sample Point 1 and Sample Point 2 (Table 2). The dissolution of the cement causes deterioration of the pipe and the release of asbestos fibers. The longer the water is exposed to the A/C pipe, the greater are the increases in pH and calcium which cause the water to become less aggressive. Therefore, the major pipe deterioration usually will occur in the sections of pipe that are located just after the water enters the A/C pipe distribution system.

The travel time or time of exposure needed to stabilize the water at the expense of the A/C pipe can occur

through either long or short lengths of pipe, however, depending on the water velocity. Therefore, a section of pipe farther from the source will not always be attacked less than pipe closer to the source because of different flow patterns through different distribution lines. Specimens of pipe cut out of one part of System A showed th[illegible]e farther out in the system was protected by stabilization of the water through the dissolution of cement from A/C pipe closer to in the same run. Other parts of System A, however, [illegible]ated that pipe both near the source and at a considerable distance from the source could be attacked equally.

This can happen when water passes through the first portion of the distribution line so quickly that it does not have time to dissolve enough cement to reduce its aggressive nature significantly before it flows farther out in the line. The water under these conditions is essentially as aggressive out in the system as it is near the source. Therefore, the pipe out in the system where flow rates have slowed, will be attacked to almost the same degree as pipe in other parts of the system that are near the source and have the same time of exposure to an aggressive water.

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Pipe Loop Studies

Two 90 foot (27 m) lengths of A/C pipe, one 4 inches (10 cm) and one 6 inches (15 cm) in diameter were tested in a recirculating system with fiber removal during each water pass. Because the recirculation reservoir was open to the atmosphere this test procedure was concluded to be non-representative of the performance of pipe in actual distribution systems. Studies of tapping in this systems were revealing, however, showing how easily fiber counts could be heavily influenced by pipe tapping when the tapping machine was not equipped with a well functioning flushing

demonstrated the importance of preventing contact between water and the atmosphere, to avoid the influence of atmospheric carbon dioxide on the chemical content of the water, when evaluating the performance of A/C pipe on a small scale.

A/C Coupon Tests

An apparatus (closed to the atmosphere) was designed (see Figure 1) to recirculate water past an asbestos-cement pipe coupon, (see Figure 2). This device is currently (Spring 1979) being used to evaluate the influence of water chemistry and various corrosion control additives on the condition (hardness) of the inner surface of asbestos-cement pipe. Although still in progress, the following has already been learned (see data summary Table 15).

Table 15. Summary of A/C Pipe Coupon Test To Date (Spring 1979)

| Experiment No. | pH | Aggressive Index | Additive | Inner Wall of Coupon Softened | |
|---|---|---|---|---|---|
| 3 | 7.0 | 9.3 | None | Yes | Figure 8 |
| 4 | 7.0 | 9.3 | Zn orthophosphate | Slightly | Figure 8 |
| 1 | 8.2 | 10.28 | None | Yes | Figure 8 |
| 2 | 8.2 | 10.28 | Zn orthophosphate | No | Figure 8 |
| 5 | 8.2 | 10.28 | Zn chloride | No | Figure 9 |
| 6 | 7.5 | 11.76 | None (slightly under $pH_s$) | Slightly | |
| 8 | 9.0 | 12.00 | None (at $pH_s$) | Very slightly | |
| 7 | 7.9 | 12.16 | None (slightly over $pH_s$) | No | |

These data lead to the following conclusions.

1. Small scale experiments can be used to evaluate performance of A/C pipe under various water quality conditions.

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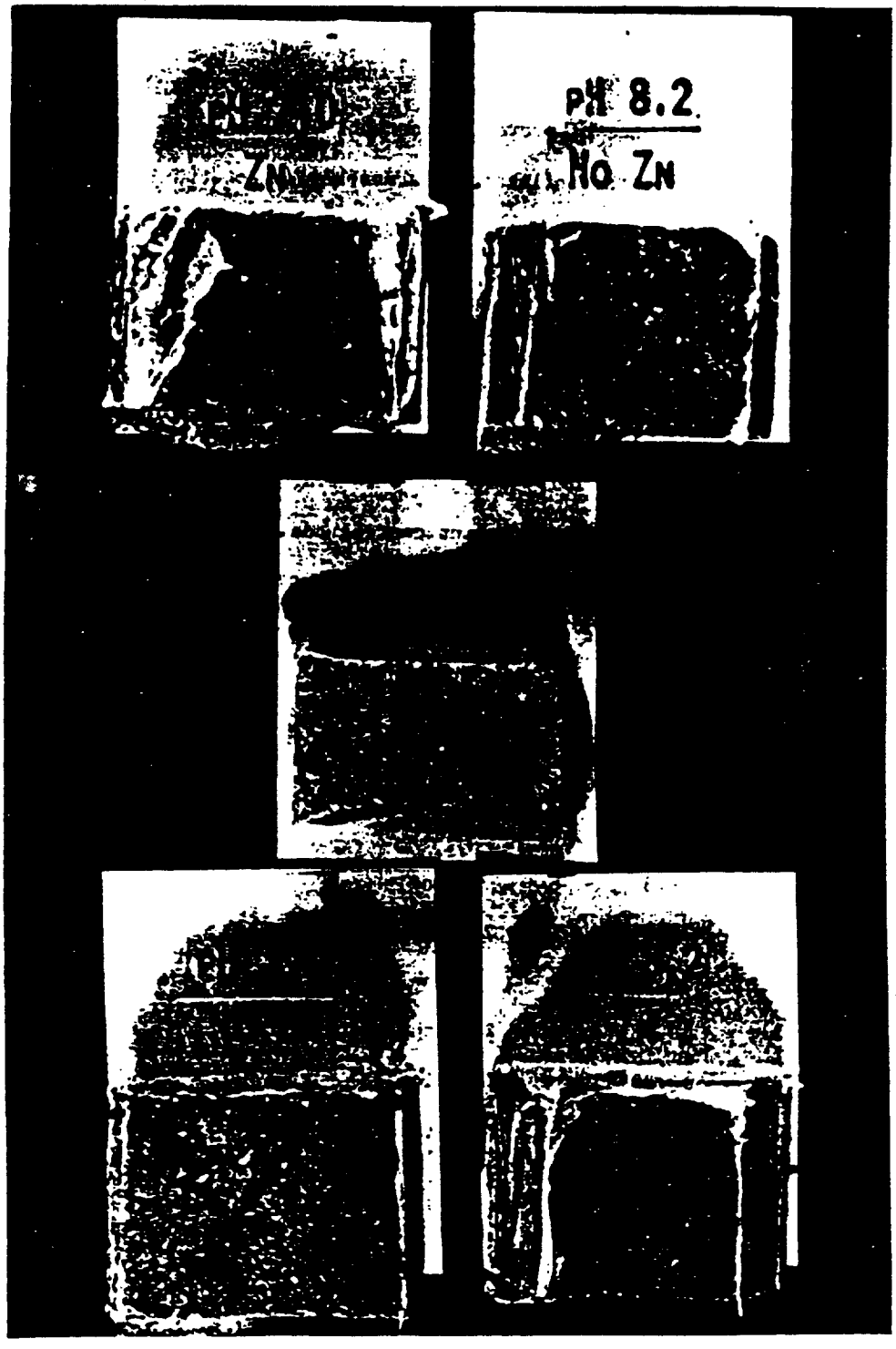


FIGURE 8 A/C PIPE COUPONS AFTER TEST

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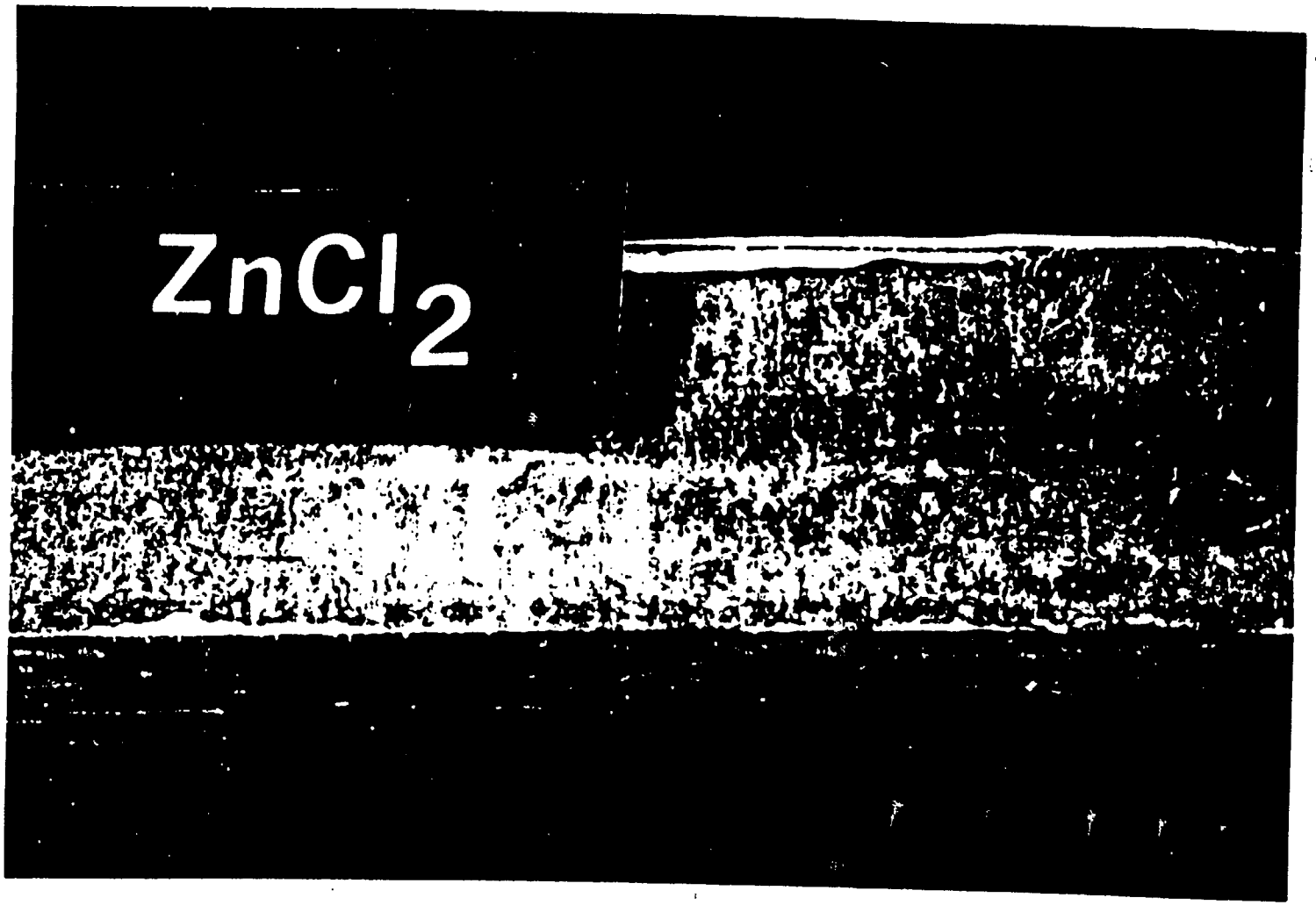


FIGURE 9 A/C PIPE COUPON AFTER TEST

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alone (Aggressive Index) are insufficient to judge whether or not A/C pipe will be attacked (softened) by a given water.

3. Substances such as iron and zinc in the water can provide considerable protection (mechanism yet undefined) to A/C pipe. With respect to zinc protection, Larson[8] has stated:

"Zinc in many natural waters containing alkalinity of 50 to 100 mg/L or more will form an insoluble protective coating of basic zinc carbonate in the pH range of 7.5 - 8.5 at room temperature or lower. In hot water tanks, there is evidence that zinc becomes cathodic to iron at temperatures above 140° to 160°F with certain types of waters. Traces of copper (0.1 mg/L) in the water can 'plate out' on zinc or iron and result in pitting."

Because these tests and most distribution systems have temperatures at or below room temperatures this mechanism may be operating. Another report on zinc protection studies was that of Courchene and Kirmeyer[9] who used zinc orthophosphate. They concluded, "Although the system was effective at reducing corrosion, the addition of phosphates to Seattle water demonstrates a potential to stimulate algae growth in open distribution reservoirs." This is another reason for studying other forms of zinc, such as zinc chloride.

4. Calcium carbonate saturation can be used to prevent attack on A/C pipe. Regarding the calcium carbonate saturation index, Larson[8] stated, "Experience has shown that the greatest weakness in the saturation index occurs with waters of relatively low alkalinity and calcium." The reason that the A/C coupon in experiment 8 at the pH of calcium carbonate saturation ($pH_s$) was very slightly softened may be because the calcium concentration and alkalinity were quite low.

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Comparison of asbestos fiber count data from systems A and J (Table 16) also demonstrates influence of pH and the calcium concentration on the release of fibers from approximately the same lengths of pipe.

Table 16. Chrysotile Asbestos Fiber Counts for System A & J

| Sample Point | System A Initial A.I. = 5.34 Chrysotile Fibers* MFL | System J Initial A.I. = 5.67 Chrysotile Fibers MFL |
|---|---|---|
| Source | BDL - 0.2 | 0.8 |
| 1 | NSS - 33 | 550 |
| 2 | BDL - 1.2 | 380 |

BDL (Below detection limit) *From various samples
NSS (Not statistically significant) MFL (Million fibers per liter)

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Although the source waters are similar in character, the difference between these two systems is that System J never had any corrective lime treatment applied. The lime treatment in System A affords considerable protection to the A/C pipe even if the treatment was not begun until after the pipe was already severely deteriorated in some sections of the distribution system.

Theoretical Considerations Laboratory tests reported above showed the effects of zinc addition, pH adjustment, alkalinity and calcium or combinations of these factors on the behavior of A/C pipe with respect to the pipe retaining its surface hardness. In order to explain what was happening chemically in these experiments and predict the action of other combinations of water quality factors, a survey of the solution chemistry of zinc in relation to coating of A/C pipe was done. A computer program was used that allows for an evaluation of multiple aqueous interactions. The computer survey resulted in "Saturation Index" diagrams and "Soluble Zinc at Equilibrium" diagrams that illustrate the final effect of the chemical interactions in the solutions. The results of this survey will be presented in Part 2 of this article and will serve to explain and to support to the laboratory coupon test results that used zinc for corrosion control as discussed herein.

Protection and Rehabilitation of Existing Systems

In an effort to determine if methods exist for protection of and rehabilitating A/C pipe, the DWRD has started two extramural research projects. Utilities G and H are participating in these studies, with utility G adding zinc to their water to determine if this treatment will reduce the asbestos fibers released from A/C pipe that is slightly attacked. Utility H with badly deteriorated pipe, but still structually sound, proposes to use the calcite coating (McCauley[4,5] process) after cleaning their mains. A report on the results at Utility G should be available by late 1979. The work at Utility H has not yet started (Spring 1979).

Future Research

A partial list of future research questions to be investigated by A/C coupon and further field testing include:

1. Will zinc provide protection at very low calcium concentrations?
2. Will zinc provide protection at lower zinc concentrations (0.1-0.2 mg/L)?
3. Will sodium silicate provide A/C pipe protection?
4. Will the protection processes that work for A/C pipe influence metal pipe?
5. What is the coating formed by iron or zinc on the A/C pipe? Mah and Boatman[7] have found by use of scanning electron microscopy that when zinc orthophosphate is used in A/C pipe experiments that zinc is found on the surface, but not phosphate. They have not, however, determined if the zinc is elemental or in a compound form.
6. Do any environmental impact problems occur with the use of zinc?
7. How do protection processes that work well experimentally perform in existing distribution systems? This work has been started in System G.

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8. Can A/C pipe coupons be used for rehabilitation studies? Deteriorated A/C pipe is to be treated without special preparation and after the surface has been scraped clean of any loose and softened materials. The tests to be tried for both the above described conditions are:

a. Calcium carbonate saturation

b. Zinc addition

c. McCauley's process[4] for calcite coating of pipe as modified by Radziul[5]. This procedure will be tried in System H, see above.

9. What other water quality factors influence the performance of A/C pipe? Research currently under way at Utility I where water with a low Aggressive Index is not attacking A/C pipe will help answer this question.

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## CONCLUSIONS

Although three extra-mural and one in-house project are still continuing, sufficient data has been collected to make the following conclusions:

1. Calculation of the Aggresive Index alone is not sufficient to predict the behavior of asbestos-cement pipe.

2. Collecting a single sample for an asbestos fiber count is often insufficient to judge the behavior of asbestos-cement pipe in a given situation.

3. Drilling and tapping of asbestos-cement pipe, if not performed with a flushing device on the tapping machine, can cause a major release of fibers into the water.

4. Metals such as zinc, iron, or manganese in the water can change asbestos-cement pipe behavior.

5. The following conditions are indicative of situations in which the water is not attacking A/C pipe:

a) An initial Aggressive Index above about 11 and,

b) No significant change in the pH or the concentration of calcium occuring as the water flows through the pipe and,

c) No asbestos fibers consistently found in representative water samples or,

d) Significant asbestos fiber counts being found in representative water samples at one time, but not another at a location where water flow is sufficient to clean the pipe of tapping debris (recent tapping can cause high fiber counts not related to pipe attack) or,

e) Significant asbestos fiber counts only being found in water samples collected from low-flow deadends or from fire hydrants (non-representative samples) and nowhere else in the system.

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6. The following are conditions indicative of situations in which the water is most likely attacking A/C pipe:

a. An initial Aggressive Index below about 11 and,

b. A significant increase in pH and the concentration of calcium occuring as the water flows through the pipe and,

c. Water not containing iron, or manganese, or possibly similar metals (note the protection caused probably by iron in System I) and,

d. Significant asbestos fiber counts being consistently found in representative water samples collected from locations where; 1) the flow is sufficient to clean the pipe of debris and 2) drilling and tapping of the pipe has not been performed near or during the sampling period and,

e. Inlet water screens at coin operated laundries becoming plugged with fibers.

7. Although inspection of pipe sections removed from the ground is the best method of assessing the condition of asbestos cement pipe, reviewing the above factors in addition to the determination of asbestos fiber counts by transmission electron microscopy (repeated sampling if possible) will aid in determining pipe conditions, if inspection is not possible.

In summary, this study has shown, thus far, that asbestos-cement pipe behaves much like other piping materials, excepting plastic, that are in common use for distribution of drinking water. If aggressive conditions toward the piping material exist, the pipe will corrode and deteriorate. If aggressive conditions do not exist toward the piping material the pipe will not corrode and deteriorate.

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