Control of Water Related Mould Corrosion in the Plastic Extrusion-Blow Process

By Timothy Keister

Introduction

Many plastic containers are presently manufactured from polyethylene and polyvinyl chloride resins by the extrusion-blow mould process. This process operates by screw extrusion of a cylinder of molten plastic, clamping of the cylinder within chilled metal blow moulds, and blowing of the plastic to the final container shape by compressed air. The blown plastic, rapidly cooled to a solid by contact with the chilled metal of the blow mould, is ejected from the mould as a finished container and the cycle repeated. Blow moulds are typically constructed as a thin beryllium copper alloy moulding surface supported by aluminum back plates. This construction maximizes transfer of heat from the molten plastic to the chilled water circulated through the mould, while minimizing the weight of the mould assembly for mechanical reasons. The transfer of heat from the molten plastic to the chilled water is a major factor in determining the speed of the production process.

Failure of a substantial number of aluminum mould back plates after less than two years service, due to apparent severe corrosion of the chilled water passages, resulted in a request from Brockway Plastics to investigate the problem, determine the cause(s), and recommend a solution. The following report discusses the problem investigation, solution formulation, and plant trial of the solution.

Investigation

The problem was defined for investigative purposes as premature failure of aluminum mould back plates due to unrepairable perforations and damage to sealing surfaces resulting in leakage of chilled water. A substantial number of back plates were found to be failing after only two years service, which was resulting in excessive replacement costs as a set of four back plates typically costs over \$2200.

A failed back plate was obtained and cut into sections for laboratory examination. Severe corrosion damage was found in o-ring seal areas, perforation failure was noted at two points, and substantial metal loss from most of the water channels was evident. Copper plating was observed in some areas of the water channels, while a gray-white deposit was present throughout. Chemical analysis of the deposit showed it to be 86.9% aluminum and 3.3% copper, expressed as the oxides.

On-site inspections and sampling of chilled water systems at four plants: Jeffersonville, Indiana; Louisville, Kentucky; La Mirada, California; and Belvidere, New Jersey were undertaken next.

The chilled water systems were found to consist of a small, 50 to 150 gallon volume, separate recirculating water system installed on each moulding machine. Chilled water is contained in a stainless steel, open top cold well and recirculated by two separate pump circuits. One pump recirculates the water through the evaporator of a 10 to 15 ton

freon cycle chiller to provide cooling, while the second pump provides the chilled water to the blow moulds. Recirculation flow rates vary, but appeared to be in the range of 50 to 100 GPM for each pump circuit.

Most of the chilled water systems observed were found to be recirculating a colored (white, green, red, or brown), turbid water. Samples of chilled water were obtained from all four plants (40 systems sampled, results attached as Appendix 1) and analyzed for pH, conductivity, calcium, iron, aluminum, copper, zinc, suspended solids, and total phosphate. Wide variations were noted in the levels of iron, aluminum, copper, zinc, and suspended solids; both in plant to plant comparisons, and in system to system comparisons within the same plant. The average concentrations of those parameters most effected by corrosion within the chilled water systems are summarized in the following table by plant.

Table I Average Chilled Water Analysis Results - mg/L

Parameter	Jeffersonville	Louisville	La Mirada	Belvidere
Iron	27	13	45	9
Aluminum	105	2.2	4.8	9.0
Copper	13.6	3.1	1.0	1.0
Zinc	8.8	10.3	22.0	8.8
Suspended Solids	469	60	166	144

Plant personnel noted that the systems were charged with soft water at Jeffersonville and Louisville, demineralized water at Belvidere, and city water at La Mirada. The following treat-

ments were employed to control corrosion; inhibited ethylene glycol at La Mirada, an oil base automotive radiator additive at Belvidere, and a proprietary organo-phosphorus treatment at Jeffersonville and Louisville. All four plants were found to be routinely cleaning moulds with an inhibited 10% phosphoric acid solution to remove scale buildup prior to each production run.

Uncleaned back plates, checked at Jeffersonville and Belvidere, had yellow-brown to gray-white deposits in the cooling water passages which when analyzed were found to be mainly aluminum hydroxide with minor amounts of calcium, iron, copper, magnesium, and silicon. Exfoliation type corrosion was noted at Jeffersonville, as well as the general corrosion damage found on the back plate examined in the laboratory. The Belvidere back plates examined showed only general corrosion damage.

Aluminum and brass corrosion coupons were installed in a chilled water system at Jeffersonville for a total time of 143 days. A corrosion rate of 18.47 mil/yr was found for aluminum, while the brass corrosion rate was .20 mil/yr.

A sample of the acid cleaning solution from Jeffersonville was obtained that had been used for six months, in which time a total of 27 moulds had been cleaned. This sample was analyzed with the following results obtained:

Table II Used Acid Cleaning Solution

Parameter	Result in mg/L
Aluminum	663
Calcium	73
Magnesium	26
Iron	13

Based on the information and analytical results obtained during the investigation, the following conclusions were reached concerning the premature failure of aluminum back plates.

- 1. The failure of aluminum back plates due to unrepairable perforations and damage to sealing surfaces is a result of water side corrosion. Most of the corrosion occurs while the back plates are in service on the moulding machines.
- 2. Galvanic couples common in the chilled water systems: aluminum-beryllium copper, aluminum-brass, copper-mild steel, and stainless steel-mild steel serve to aggravate corrosion of the anodic metal.
- 3. Deposits found in the back plate water channels consist mainly of aluminum corrosion products, with minor amounts of iron, copper, magnesium, silicon, and calcium.
- 4. Acid cleaning for removal of water channel deposits is necessary to maintain acceptable production rates, but results in increased corrosion rates due to exposure of a fresh aluminum surface to the chilled water following each acid cleaning. The cycle of corrosion, deposition, and acid cleaning is thus repeated until the back plate fails.
- 5. The corrosion inhibitors in use at three of the plants checked did not appear to be effectively controlling corrosion of back plates and chilled water system components.
- 6. The high suspended solids level found in almost all of the chilled waters tested indicates that fouling of the heat transfer surfaces within the moulds could be expected.

On the basis of these conclusions, it was decided to proceed with development and plant demonstration of a chemical corrosion inhibitor for use in the chilled water systems.

Product Development

The initial requirements set for the corrosion inhibitor were that it function effectively in soft, chilled water (35 to 55°F), present no environmental control problems, be of reasonable cost, be easy to implement and control at the plant level, and provide excellent corrosion control for systems constructed of copper, aluminum, brass, carbon steel, beryllum copper, and stainless steel. A literature search on formulation of a corrosion inhibitor to meet these requirements turned up several data sources. In particular, papers by Robitaille, (1) Vukasovich and Sullivan (2); Rowe, Chance, and Walker (3); and Wiggle, Hospadaruk, and Styloglou (4) were utilized in deciding which specific components were to be included in the formulation.

As Brockway is not a chemical formulator, a joint project was set up with Mr. Thomas Issac of Wright Chemical Corporation to devise an appropriate formulation. A corrosion inhibitor containing molybdate, nitrate, silicate, benzotriazole, and polymeric glycol as active components was subsequently formulated and designated as CB-2004 by Wright. The active components are utilized for the following functions:

- Molybdate, is a general purpose inhibitor that is especially effective with ferrous alloys in an aerated environment. (1)
- Nitrate, is a specific corrosion inhibitor for aluminum. $^{(4)}$

- Silicate, is a general purpose inhibitor that is especially effective on aluminum. (3)(4)
- Benzotriazole, is a specific corrosion inhibitor for copper and its alloys. (6)
- Polymeric glycol, is a general metal surface cleaner which enhances the action of corrosion inhibitors (5).

Laboratory tests of CB-2004, by Wright Chemical, showed an aluminum corrosion rate reduction of 89.3% (13.31 mpy to 1.43 mpy) when aluminum coupons galvanically coupled to copper were tested in untreated and CB-2004 treated water. On the basis of the laboratory tests, it was decided to proceed with a plant demonstration of the CB-2004.

Plant Demonstration

The Belvidere, New Jersey, extrusion-blow mould plastic container plant was selected as the best location for the plant demonstration of CB-2004 due to its proximity to the Brockway Central Laboratory, inclusion in the Brockway water systems control program, use of Wright Chemical as the water treatment chemical supplier, and history of aluminum back plate corrosion/fouling problems.

The plant demonstration at Belvidere consisted of three separate trials of CB-2004. Trial #1 involved treatment of the chilled water systems on machines 4, 7, 9, and 16 with CB-2004, while utilizing machines 1, 2, 11, and 14 as untreated controls. This trial started on 16 May and was completed on 28 June, a total of 44 days.

Trial #2 was initiated on 28 June and was completed on 20 August, a total of 54 days. The chilled water systems on machines 1, 6, 8, and 10 were treated with the CB-2004 during the trial, while machines 2, 7, 9, and 12 were utilized as untreated controls.

Trial #3 was conducted by treating the chilled water system on machine 1 with CB-2004, while using machine 6 as the untreated control. This trial was initiated on 21 August and completed on 20 September, a total of 31 days.

Selection of which machines to utilize for any given trial period was based upon the projected production over the trial period. Machines with the maximum production time were selected for both treatment and control use. Trial #2 did have a two week period, just after July 4, when the entire plant went out of producton for inventory control purposes.

The procedure implemented for treated chilled water systems on all three trials involved blowdown of each system for four hours once a week, and manual addition of 200 ml CB-2004 directly to the system cold well immediately after blowdown completion. Control chilled water systems were given the same weekly four hour blowdown, with no treatment addition.

At 200 ml CB-2004 addition, the level of treatment as product was targeted at 725 mg/L given the average water volume of 90 gallons for a chilled water system. This amount of product was expected to result in the following levels of active components in the treated, chilled water systems.

Table III Active Component Levels

Component	Level	As
Molybdate	20 mg/1	Мо
Nitrate	9 mg/l	NaNO ₃
Silicate	5 mg/l	sio_2
Benzotriazole	1.9 mg/l	BZT
Polymeric Glycol	18.8 mg/l	PG

Brass, aluminum, copper, and mild steel corrosion coupons were installed in each treated and control chilled water system at the cold well using plastic holders and immersion racks. The 3/8 inch diameter rod coupons were immersed in the chilled water for the entire period of each trial, and then analyzed using accepted NACE methods.

Water samples were obtained from all chilled water systems utilized in Trial #1 just prior to implementation, and analyzed for pH, conductivity, calcium, iron, aluminum, copper, zinc, and suspended solids using procedures from Standard Methods, 15th edition ⁽⁷⁾. Water samples were obtained from each of the chilled water systems utilized in the three trials at the trial conclusion. These samples were analyzed for the same parameters, plus molybdenum, via the same methods as the initial sample set.

Results

The corrosion coupon results (attached as Appendix III) from the three trials are summarized in the following Table IV as averages for treated and control chilled water systems.

Table IV Average Corrosion Rates As Mils/Year

Trial #1	Aluminum	Steel	Brass	
Untreated	7.61	9.33	.50	
Treated	1.23	.80	.04	
% Reduction	83.8	91.4	92.0	
Trial #2	Aluminum	Steel	Brass	
Untreated	2.80	5.82	.39	
Treated	2.80	5.84	.08	
% Reduction	0.0	-0.3	79.5	
Trial #3	Aluminum	Steel	Brass	
Untreated	13.78	17.06	1.09	
Treated	2.30	.70	.56	
% Reduction	87.3	95.9	48.6	

Chemical analysis results (attached as Appendix IV) from the initial sampling and those at the conclusion of each trial are summarized as averages in the following Table V.

Table V Average Chilled Water Results

Initial Sampling - Machines 1, 2, 4, 5, 8, 11, 14, and 16

Parameter pH cond Ca Fe Al Cu Zn TSS

Average Value 7.67, 333, 12.4, 5.1, 29.5, 2.4, 2.7, 165

Trial #1 - Machines 4, 9, and 16

Parameter pH Cond Ca Fe Al Cu Zn Mo TSS

Average Value 8.24 657 10.5 .72 .9 .40 .47 31.8 13

% Reduction 86.3 96.9 83.3 92.1

Trial #2 - Machines 1, 6, 8, and 10

Parameter pH Cond Ca Fe Al Cu Zn Mo TSS

Average Value 7.48 204 9.8 14.4 .9 1.60 .97 16.8 25

% Reduction -182.3 96.9 33.3 84.8

Trial #3 - Machine 1

 Parameter
 pH
 Cond
 Ca
 Fe
 Al
 Cu
 Zn
 Mo
 TSS

 Value
 8.04
 560
 2.2
 1.06
 ND
 .18
 .14
 7.2
 ND

 % Reduction
 78.4
 100
 92.5
 100

pH as su Cond. as mmhos Balance as mg/l

It was observed that corrosion coupons from treated chilled water systems had substantially less fouling than those from untreated system. Several sets of corrosion coupons from treated systems appeared in "as new" condition when removed, compared to the heavy fouling found on all untreated system corrosion coupons.

Discussion

The corrosion coupon and chemical analysis results from Trials #1 and #3 show a substantial reduction in corrosion rates and corrosion products for the CB-2004 treated chilled water systems. Trial #2 presents contrary results in that no reduction in aluminum, or mild steel, corrosion rates and corrosion products was found. This problem is resolved by noting that the amount of molybdenum (a major component of CB-2004) found in the Trial #2 water samples is equivalent to no treatment in half of the treated systems. We believe that this lack of treatment, coupled with two weeks of no flow or treatment resultant from the noted two week plant shutdown during the trial, explains the lack of corrosion control shown in Trial #2.

The Trial #2 results demonstrate an important point, a chemical corrosion inhibitor will only work if applied at the correct level in a properly operating system. Lack of a sufficient level of CB-2004 and static water for a two week period resulted in average corrosion, and corrosion product, levels equal to untreated chilled water systems.

Considering the initial requirements set for the corrosion inhibitor, the trials at Belvidere plant have demonstrated that CB-2004 functions in aerated, chilled water systems to control corrosion of aluminum, copper alloys, and mild steel to acceptable levels when compared to our respective standards of 2 mil/yr, .3 mil/yr, and 2 mil/yr average for these materials.

The CB-2004 treatment used at Belvidere cost about \$1.09/week per moulding machine for the inhibitor and utilized existing plant labor for implementation. If we assume that mould back plate life is increased from two years to ten years, with a replacement cost of \$2200, our daily cost for replacement drops from \$3.06 to \$.77, including the cost of CB-2004 treatment. The decrease of \$2.29/day in replacement cost results solely from the substantial improvement in mould back plate life projected with use of CB-2004.

We also expect that improvements in process control and forming machine speed will be obtained with use of CB-2004 due to the decrease in fouling projected. It would be an interesting experiment to run the same forming machine with, and without, CB-2004 treatment to document exactly how much improvement could be obtained in these areas.

Environmentally, all of the active components in CB-2004 are presently acceptable for discharge to sanitary sewer systems at the recommended usage level. Due to the low toxicity of molybdate (1), nitrate (8), polyethylene glycol (9), and benzotriazole (8); and the non-toxic nature of the silicate (10), it is expected that no future environmental regulations will impact on use of CB-2004.

Note should be made that the pH (13.1-13.5 s.u.) of neat CB-2004 renders it both a corrosive caustic during handling, and a hazardous waste for disposal, under OHSA and RCRA regulations respectively.

The weekly blowdown and treatment addition procedure used during the Belvidere Plant demonstration was believed to be the best method for implementation of a corrosion inhibitor program in a plant with a large number of small, independent water systems. The experience of Trial #2 shows that some level of control testing and management review is necessary to obtain satisfactory results. Use of random control tests of treated chilled water, with the test results logged for management review, would likely provide the desired increase in control at a minimum of additional cost.

Control testing could be based on nitrate, molybdate, or silicate as these materials are present in CB-2004 treated water at levels where low cost test kits can be utilized. Molybdate is the preferred test parameter since it is not present in any known makeup water source, thus eliminating blank correction for amounts in the makeup water and greatly simplifying the test procedure.

Conclusions

- 1. The premature failure of aluminum mould back plates due to unrepairable perforations and damage to sealing surfaces is caused by water side corrosion during production. The corrosion appears to be common, in greater or lesser degree, to all plastic container plants using chilled water for cooling of multi-metal blow moulds.
- 2. An environmentally acceptable corrosion inhibitor (CB-2004), developed jointly with Wright Chemical Corporation, has been tested and found effective for control of aluminum, steel, copper, and brass corrosion in an operating plant.

- 3. The economics of treating chilled water systems with CB-2004 for corrosion control are favorable. Assuming a resultant back plate life increase of 8 years (from 2 to 10 years), we have calculated an overall replacement cost reduction of \$2.29/day per back plate set.
- 4. The recommended operating procedure consisting of weekly system blowdown, shot feed of CB-2004, control tests, and management review of control test logs is deemed adequate to insure acceptable program results.
- 5. Chilled water systems treated with CB-2004 were observed to have substantially less fouling of corrosion coupons than untreated control systems. Since fouling of heat transfer surfaces within moulds decreases the rate of heat transfer from plastic to chilled water, a decrease in fouling is expected to improve both process control and production speed.

Recommendation

Due to the fact that various dispersants to further control fouling can likely be incorporated into the formula of CB-2004, it would be of interest to quantify the relationship between water side fouling of blow moulds and production speed. Once such a relationship was quantified, it would be possible to examine the cost-benefit of additional dispersants in the CB-2004.

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Appendix I Chilled Water Analysis

Plant #36, Louisville

Machine	Ph	Cond.	Ca	Fe	Al	Cu	Zn	TSS	T.04
_	su	mmhos	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/1
1/2	6.9	525	36	8	1.7	. 5	13.7	42	2.8
3/4	7.5	470	15	20	1.2	14.9	5.4	59	1.0
5/6	7.4	450	11	23	1.5	1.0	8.2	84	4.0
7/8	7.1	390	30	6	2.0	. 5	7.4	35	1.8
9/10	7.0	410	37	14	6.5	1.6	25.0	115	6.6
Sterlco	9.5	<u> 365</u>	<u>25</u>	<u>9</u>	ND	<u>. 2</u>	1.8	<u>25</u>	1.5
Average	7.6	435	26	13	2.2	3.1	10.3	60	3.0

Plant #37, Jeffersonville

Phosphate Treatment

Machine	Ph	Cond.	Ca	Fe	Al	Cu	Zn	TSS	T.PO4
	su	mmhos	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1
1	7.9	760	9	8	19	1.4	3.1	78	.8
2	8.0	730	8	62	41	8.2	5.2	300	6.3
3	8.1	755	12	6	48	5.7	4.1	195	.8
4	7.6	610	36	35	338	36.7	32.0	1434	6.0
5	7.9	740	11	21	114	12.2	7.0	432	1.9
6	8.0	680	16	21	46.	6 4.5	3.0	210	. 2
7	7.6	730	16	2	1.	6.1	.02	16	32.0
8	8.0	640	13	58	233	28.5	13.5	1091	4.1
9	7.5	465	28	<u>26</u>	103	<u> 26.1</u>	11.4	461	4.1
Average	7.8	679	17	27	105	13.6	8.8	469	5.9

Plant #33, Belvidere

Soluble Oil Treatment

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Machine	pН	Cond.	Ca	Fe	Al	Cu	Zn	TSS
	su	mmhos	mg/1	mg/l	mg/1	mg/1	mg/1	mg/1
1	8.0	850	14	80	7.5	2.9	2.7	172
4	8.3	575	3	.1	1.0	.04	. 1	13
5	8.2	560	5	.1	. 5	.03	. 2	ND
7				1	.9	. 4	. 2	ND
8	7.9	550	17	5	2.1	. 3	1.0	22
9	8.0	600	3	2	2.6	. 7	.8	643
10	7.6	300	8	1	1.8	1.0	. 3	472
14	7.6	520	15	5	69	2.4	6.9	579
15	8.0	520	6	2	4.4	. 3	. 7	48
16	8.0	640	6	2	5.4	. 7	1.3	36
17	7.4	325	14	8	12.2	3.0	5.3	112
18	7.1	340	7	<u>2</u>	<u>.3</u>	.4	2.1	4
Average	7.9	526	9	9	9	1.0	8.8	144

Plant #38, La Mirada

Inhibited Ethylene Glycol Treatment

Machine	pН	Cond.	Ca	Fe	A1	Cu	Zn	TSS	T.PO4
	su	mmhos	mg/l	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1
1	8.08	2050	86	10.2	3.8	.6	14	99	3.48
2	7.78	1850	106	.6	<.2	.1	3	1	.01
3	7.41	900	32	79.8	1.7	.9	17	161	3.03
4	7.47	1280	88	34.0	1.5	. 3	11	78	1.46
5	7.15	1200	77	51.0	1.3	. 2	12	138	.90
6	7.28	1000	50	138	13.9	.9	8	367	8.18
7	7.87	1370	83	36	6.7	1.1	15	140	4.37
8	6.74	1350	27	10	.8	.1	20	39	1.40
9	6.57	1670	17	12	1.5	. 2	4	145	47.2
10	8.77	1050	22	39	.8	. 4	8	221	18.1
11	7.58	1400	72	54	6.6	1.5	28	222	7.23
12	8.06	1000	68	27	5.2	1.3	18	129	2.47
13	7.72	815	76	102	13.6	4.9	150	454	10.3
14	7.95	1680	<u>68</u>	<u>31</u>	9.4	.8	<u>6</u>	<u>126</u>	3.42
	7.60	1330	62	45	4.8	1.0	22	166	7.97

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Appendix II Raw Makeup Water Analysis

Plant Jeff	ersonville	Louisville	Belvidere	La Mirada
Parameter pH-s.u.	7.82	8.14	7.95	7.95
Conductivity- mmhos	700	390	570	420
Total Alkal- inity-mg/l	244	86	222	168
Total Hard- ness - mg/l	342	153	310	94
Dissolved solids-mg/l	470	267	347	321
Calcium-mg/l	89	43	73	26
Magnesium-mg/l	29	11	31	7
Iron-mg/l	.21	.77	.03	.10
Copper-mg/l	.07	ND	.02	.06
Sodium-mg/l	26	19	11	67
Silicon-mg/l	9	4	5	9.9
Chloride-mg/l	44	23	14	19.9
Sulfate-mg/l	65	22	35	72.8
Phosphate-mg/l	. 1	• 3	ND	ND
S.I. at 90°F	+.84	+.41	+.85	+.29
C.I.	3.02	.30	1.73	4.67

Appendix III Corrosion Coupon Results

Trial #1

Untreated		Results as mil/year	
Machine	Steel	Brass	Aluminum
1	11.63	. 28	7.10
2	11.82	. 35	17.00
Treated		Results as mil/year	
Machine	Steel	Brass	Aluminum
4	. 25	.03	1.18
7	. 27	.05	1.22
9	2.19	.03	1.03
	2.4.7		
<u>16</u>	<u>.47</u>	<u>.05</u>	1.48
<u>16</u> Average			

Trial #2

Untreated		Results as mil/year	
Machine	Steel	Brass	Aluminum
2	6.20	.18	2.02
7	7.03	1.16	6.70
9	5.01	.04	1.31
12	<u>5.03</u>	.17	1.16
Average	5.82	.39	2.80

Trial #3

U	ntreate	Resu	ults as mil/year									
	Machine		teel		Cop	per	Aluminum					
	6		17.06		1.	.09	13.78					
	Treate	eđ	Results as mil/year									
	Machine		teel		Cor	pper	Aluminum					
•	1		.70		• 5	56	2.30					
Appendix IV												
Water Sample Analysis Results - mg/l*												
Initial Sampling Data												
Machines	pН	Cond.	Ca	a F	e	A1	Cu	Zn	TSS			
1	7.33	450	12	.8 16	. 7	1.6	1.10	1.04	111			
2	7.45	160	10	. 2	.5	ND	.06	.19	3			
4	7.50	75	4	. 9	.1	ND	.08	.22	1			
5	7.49	360	8	. 4	. 4	. 3	.07	.30	3			
8	8.29	400	9	. 2	. 7	3.4	.24	.43	26			
11	7.86	395	25	.8	. 1	. 2	.05	.18	4			
14	7.48	475	18	. 7	.7 1	34	3.75	4.44	671			
16	7.94	<u>345</u>	9	<u>.5</u> <u>12</u>	2.3	96.2	<u>14.2</u>	14.4	504			
Average	7.67	33	12	. 4 5	.11	29.5	2.4	2.7	165			
Trial #1 - Treated												
Machines	рĦ	Cond.	Ca	Fe	Al	Cu	Zn	Mo	TSS			
4	8.50	715	11.0	.05	1.0	.39	.40	37.1	ND			
9	7.94	690	9.0	1.94	1.0	.47	.87	44.0	37			
16	8.27	<u>565</u>	11.5	<u>.17</u>	<u>.8</u>	<u>.35</u>	.15	14.2	11			

657

8.24

Average

10.5

.72

. 9

.40

31.8

13

Trial #2 - Treated

Machines	pН	Cond.	Ca	Fe	Al	Cu	Zn	Mo	TSS		
1	7.77	226	10.1	24.2	2.9	.98	1.14	7.1	44		
6	7.88	106	10.0	30.2	.8	5.24	.86	.6	56		
8	7.90	450	14.9	3.08	ND	.07	.90	59.1	ND		
10	6.38	<u>32</u>	4.1	.31	ND	.12	.96	.4	ND		
Average	7.48	204	9.8	14.4	.9	1.60	.97	16.8	25		
Trial #2 - Treated											
Machines	pН	Cond	Ca	Fe	Al	Cu	Zn	Mo	TSS		

1 8.04 560 2.2 1.06 ND .18 .14 7.2 ND

^{*} pH as su Cond. as mmhos