**Evaluation of the Brinecell® Electrochemical Oxidation
Unit for Destruction of Noncyanide Strippers and
Other Colored Compounds
in Wastewaters**

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Evaluation of the Brinecell® Electrochemical Oxidation Unit for Destruction of Noncyanide Strippers and Other Colored Compounds in Wastewaters

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ABSTRACT

The noncyanide strippers used in the plating operations at Kelly Air Force Base, in San Antonio, Texas, develop an intense red color during use. Currently, the spent strippers cannot be treated in the Industrial Wastewater Treatment Plant because, even after biological treatment, the color remains too high for discharge. The Brinecell® process was evaluated for its application in treating the spent stripping solutions. The Brinecell® produces strong oxidizing agents that could treat the color causing compounds. The Brinecell® process was used to treat a 1 to 400 dilution of spent Clepo 204-T at 50°C and 60 g/L salt. After 8 hours of treatment, the color remaining was 8 units and the solution appeared colorless. Treatment of the Metalx B-9 reduced the color to 60 units. The effect of salt concentration, solution temperature, and solution pH was evaluated on the Brinecell® treatment process.

SUMMARY

The noncyanide stripping solutions used in the plating shop at Kelly Air Force Base (AFB), in San Antonio, Texas, have chemical oxygen demands (COD) concentrations as high as 350,000 mg/L with heavy metal concentrations as high as 10,000 mg/L. Although, the noncyanide strippers work better than the cyanide strippers, are less hazardous to the user, and give longer bath lifetimes, they still develop an intense dark red color during use. Several methods of treatment have not resulted in destruction of the color forming complexes.

In the Brinecell® process ozone, chlorine, chlorine dioxide, sodium hypochlorite, hydrogen peroxide, and the free-radicals of these oxidizing agents are produced. Because of the strong oxidizing potentials of the chemicals produced by the Brinecell® reaction, it was believed that the Brinecell® process would be an efficient and economical treatment of chemicals causing red water in the stripping process. The objective of this program was to determine the application of the Brinecell® process in treating the spent stripping solutions and to determine the parameters for treating the spent waste.

A Brinecell® Model 301 was used to evaluate the Brinecell® process. The application of the Brinecell® for treating the noncyanide strippers was evaluated as a function of the stripper concentration, temperature, salt concentration, and pH for the Clepo 204-T. In addition, the process was evaluated for treating the Metalx B-9 stripper. The Brinecell® Model 301 removed the color to 8 units for a 1 to 400 dilution of the Clepo 204-T stripper and to 60 units for the Metalx B-9 stripper. At 8 color units, the solution appears colorless.

Carbonate formation in the treatment of the Metalx B-9 slowed the color removal process, which will require incorporating the carbonate removal process into a full-scale treatment.

Precipitates are formed in the treatment of the strippers. Treatment with the Brinecell® process and filtration decreased the COD of the stripper solution by 72%, the Total Organic Carbon by 85%, and the nickel concentration by 90%.

It is recommended that a full-scale Brinecell® treatment process incorporating the carbonate removal process and a filtration process be designed and optimized for implementation at Kelly AFB. Treatment of the stripper would eliminate the current stripper disposal cost of \$150,000 per year.

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Evaluation of the Brinecell® Electrochemical Oxidation Unit for Destruction of Noncyanide Strippers and Other Colored Compounds in Wastewaters

1. INTRODUCTION

A number of metal processing solutions at Kelly Air Force Base (AFB) were observed turning dark red with use. This was particularly obvious with the cyanide containing stripping solutions used in the plating shop. In addition, biodegradation of the solutions after cyanide destruction did not remove the dark red color.

In an effort to minimize the generation of hazardous wastes, the elimination of cyanide was mandated by the Air Force several years ago. Substitution of cyanide with noncyanide strippers at Kelly AFB has resulted in waste reduction by eliminating the toxic cyanide metal stripping waste. However, the cyanide process solutions were eliminated by substituting commercial products that contain a large concentration of organic materials. Although waste toxicity and volume have been reduced, the alternative solutions still produce wastes containing high concentrations of heavy metals, ethylenediamine, nitroaromatics, and other organics that were not present in the cyanide strippers. The spent noncyanide strippers have chemical oxygen demands (COD) concentrations as high as 350,000 mg/L with 10,000 mg/L heavy metals. Although the noncyanide strippers work better than the cyanide strippers, are less hazardous to the user, and give longer bath lifetimes, they still develop an intense dark red color during use. Several methods of treatment, including biological, have not resulted in destruction of the color forming complexes.

1.1 Objective

The objective of this program was to evaluate the application of the Brinecell® electrochemical process for the destruction of the color forming complexes. In addition, the chemical operating parameters for the process were determined.

1.2 Background

1.2.1 Noncyanide Strippers

The program to replace cyanide metal containing metal stripping solutions in the plating shop at Kelly AFB has moved into the demonstration phase.¹ During this program, 35 commercial strippers, three Air Force process solutions, and a generic nickel stripper were tested. If a stripper proved effective in laboratory testing, field tests at volumes of 20 to 100 gal were used to optimize variables such as pH, temperature, longevity, metal loading, and regeneration. The most effective products were implemented into the plating shop at Kelly AFB.

The major organic component of each noncyanide metal stripping product targeted for implementation was identified, and the biodegradability of the component evaluated.

Ethylenediamine and nitroaromatic corrosion inhibitors represent the major organic constituents of a number of noncyanide metal strippers recommended for implementation. Tests of the individual components indicated the current Kelly AFB activated sludge was not acclimated to ethylenediamine. However, the activated sludge contained three different microbial strains that could acclimate to and biodegrade ethylenediamine.¹

Currently, three noncyanide strippers are being used for stripping in Building 301 at Kelly AFB. These are the Clepo 204-T manufactured by Frederick Gumm Chemical Company, Inc., the Metalk B-9 manufactured by Metalk, Inc., and Rostrip Electrolytic Stripper 999-SP manufactured by McGean-Rohrco, Inc. The volume of the strippers used are given in Table 1. In addition to these strippers, a generic stripper has been developed by EG&G Idaho, Inc.²

The Clepo and Metalk noncyanide strippers are currently being disposed of as a hazardous waste at a cost of \$1.35/lb due to their high COD concentration and the fact that their disposal in the IWTP generates a colored water that cannot be discharged. At the current usage rate, this represents an annual disposal cost of approximately \$150,000/year. These wastes are pumped to a carboy, and when the carboy is full, the waste is removed by a certified hazardous waste disposal company. The time for disposal after a stripper has been defined as spent can be as long as 2 months.

The Clepo 204, Metalk B-9, and EG&G Idaho's generic nickel strippers all turn dark orange or red with use.² However, two strippers do not change colors: Nickel-Sol and Rostrip 999-SP. The distinction that sets these two products apart are that neither contain a nitroaromatic compound in their formulation. It is believed that the species responsible for the color is either sodium 3-nitrobenzenesulfonate (found in Metalk B-9 and EG&G Idaho's generic nickel stripper, or sodium 3- or 4-nitrobenzoate (found in Clepo 204).² The components that are found in these color causing noncyanide stripping solutions are given in Table 2. The color formation is not necessarily dependent on the stripper usage. The red orange color develops upon initial make up of the stripper when it is heated for use. EG&G Idaho has identified the color causing compound as 3,3'-benzenesulfonate.²

Aerobic biological treatment of the spent stripping solutions in an activated sludge column did not result in the color removal. Neither did anaerobic treatment. Chemical treatment with hydrogen peroxide, ammonium persulfate and sodium thionite were evaluated.² Oxidative treatment with persulfate made the solutions turn a darker color. Sodium thionite lightened the color but did not remove the color. Although, during some of the tests, the color was removed, it reappeared within 1 day when it was exposed to air or when the pH was adjusted to those found in the Kelly AFB Wastewater Treatment Plant (i.e., pH 9.5 to 10).

1.2.2 Chemical Oxidation

Fenton Process. Oxidation of organic waste with hydrogen peroxide (H_2O_2) is usually a slow process. However in the presence of a catalyst, the oxidation process proceeds rapidly.³ Catalysts include ferrous iron, copper, aluminum, and chromium. Ferrous iron is a good selection because it is not listed as a heavy or toxic metal and its use and subsequent precipitation does not create further hazardous waste problems. Hydrogen peroxide in combination with a ferrous iron salt is commonly referred to as Fenton Reagent. This reagent acts as an oxidizing agent through the formation of hydroxyl free radicals.²

Table 1. Kelly AFB noncyanide stripper usage.

Noncyanide stripper	Tank size (gal)	Disposal dates	Disposal quantity	Total volume (gal)	Disposal frequency
Clepo 204-T	700	2/22/93-2/15/94	6 tanks	4,200	2 months
Metalk	2,500	2/14/92-2/14/93	3 tanks	7,500	4 months
Rostrip	700	6/26/92-2/19/93	2 tanks	1,400	4 months

Table 2. Components found in the noncyanide strippers.

Generic stripper	Ethylenediamine Sodium 3-nitrobenzenesulfonate Sodium thiocyanate Nitric acid
Clepo 204	Ethylenediamine 3- or 4-nitrobenzoic acid N,N'-diethylthiourea pH control agents (sodium hydroxide, nitric acid)
Metalk B-09	Glycine Sodium 3-nitrobenzenesulfonate Sodium carbonate Sodium thiosulfate

Optimum oxidation with the Fenton Reagent normally occurs at a pH of 3 to 7. However, in the presence of acetate or phosphate buffers, the reaction proceeds slower in these pH ranges. The formation of intermediate products produces a dark brown color. At the completion of the reaction, the solution is a yellow or orange color due to the presence of the ferric iron. The ferric iron can be precipitated by increasing the pH either with lime or caustic. There is some co-precipitation of the remaining organics. Depending on the effluent discharge requirements, further treatment may be required to reduce the COD to discharge limits. The effluent, however, may be applicable for discharge to a domestic sewage treatment plant or biological industrial waste treatment plant.

The Fenton Reagent has been used to treat stripped refinery effluent and steel plant effluent. The stripped refinery effluent had an initial COD due to phenol of 280 mg/L with a total initial COD of 970 mg/L. Nine moles of hydrogen peroxide and 1 mole of ferrous ammonium sulfate was added per 1 mole of phenol. The COD remaining due to phenol at pH 4 and 50°C for 30 minutes was 2 mg/L. The total COD remaining was 246 mg/L.³

Ozonation. If sufficient ozone is added essentially all organic compounds can be oxidized to carbon dioxide.⁴⁻⁹ The source of the ozone can be either electrical production with an ozone

generator or use of ultraviolet light to convert the oxygen available in the wastestream to ozone. The use of an ozone generator, although requiring more initial capital cost, is a more effective method of treatment. Generation with ultraviolet light is limited by the solubility of oxygen in the water.^{4,5} The ozone generator processes either air, oxygen enriched air, or pure oxygen into ozone. The ozonation process can be enhanced by the addition of hydrogen peroxide to the wastestream.

Complete and efficient ozonation is dependent on the type of waste, degree of oxidation desired, reactor or contactor configuration, and contact time. Contactor configurations may include bubble towers or packed columns. The presence of carbonates may inhibit ozonation at high pH.

Approximately 2 to 6 mg/L ozone are required per 1 mg/L phenol. Solutions with higher initial COD concentrations react more rapidly. The ozone demand to oxidize phenol at a pH of 12 is half that required at a pH of 7.⁶

The degree of ozonation desired is dependent on what process may follow the ozonation process. For example, if a biological treatment process is available, it may be desirable to only treat the wastestream with ozone to degrade the organics to the level where they are not toxic to the biological system or can be degraded to discharge limits by the biological system. Ozonation of high-molecular weight bioreactory organic compounds (such as humic acid) produces lower-molecular weight, more biodegradable substances.⁷ At the same time, more oxygen is added to the wastestream for biological treatment.

Treatment of groundwater contaminated with trichloroethylene (TCE) and tetrachloroethylene (PCE) has been demonstrated on a 2,000 gpm unit.^{8,9} The groundwater was contaminated with 200 µm TCE and 20 µm/L PCE. To achieve 80 to 90% destruction of the contaminants, 4 mg/L ozone was required with a ratio of hydrogen peroxide to ozone of 0.5% by weight. The capital cost for the ozone generator was \$85,000. Hydrogen peroxide cost was approximately \$1.00/lb.⁹

Hypochlorite Oxidation. At one time, the majority of sodium hypochlorite was manufactured electrolytically. Currently it is a by-product of the chlor-alkali industry.¹⁰ However, there are times when small volumes of hypochlorite are required and the cost of transportation forces the use of electrolytical production. These uses can include sterilization of potable water, stopping algae growth in cooling systems, sewage treatment, conditioning of swimming pools, disinfection of equipment in the food and dairy industry, and deodorization of the air from sewage or tobacco treatment plants.¹⁰ The reaction proceeds as follow in the electrolytic cell:¹⁰

At high OCl⁻ concentrations, elevated temperature, and turbulent flow conditions, the mass transport reaction becomes important:¹⁰

However, if the salt (NaCl) concentration is low, the temperature is low, or in the presence of too small of electrolyte movement, the reaction rate may be low and oxygen evolution can occur:¹⁰

At high hypochlorite concentrations and high temperatures, loss of OCl^- can occur by the following reaction:¹⁰

Brinecell® Process. Brinecell® Inc., in Salt Lake City, Utah, offers a process for the oxidation of the organic compounds similar to ozonation. The Brinecell® consists of an electrolytic cell where patented Brinecell® electrodes are used to produce ozone, chlorine, chlorine dioxide, sodium hypochlorite, hydrogen peroxide, and the free-radicals of these oxidizing agents. These agents are known to oxidize oxidizable organics, while they deink, decolor, and deodorize. Sodium chloride is added to the solution and a chloride-chlorine-chloride cycle takes place in the electrolytic cell. The Brinecell® process uses an electrode to create hydrogen peroxide, ozone, chlorine, and hydroxyl radicals to oxidize the organics present in the wastewater. The oxidation is dependent on the salt (sodium chloride, NaCl) concentration, pH of the solution, organic compounds being oxidized, and other contaminants and their concentration that may be present in the wastewater. The time required for oxidation is dependent on the type and concentration of the organics present in the waste. A partial list of the effluents processed in the Brinecell®s is shown in Table 3.¹¹

The Brinecell® process can operate by recirculating a stream of the effluent through the cell with saline injection (batch process), or on a continuous basis. The volume, concentration of the waste, and type of organic being treated determine the size of the electrolytic cell and operational requirements. The Brinecell® can be operated at various voltages (10 to 60 V) and amperages (as low as 20 to as high as 800) depending on the design of the cell. The operation can be low voltage with high salt concentrations or can be high voltage with low salt concentrations. The salt can be injected as a saline solution or rock salt can be used.

1.3 Scope

Because of the strong oxidizing potentials of the chemicals produced by the Brinecell® reaction, it was believed that the application of the Brinecell® process would be an efficient and economical treatment for chemicals causing red water in the stripping process at Kelly AFB. During this program, the application of the Brinecell® process to the treatment of the spent stripping solutions was demonstrated. In addition, the chemical and physical parameters for treatment of the spent waste was defined using the Brinecell® Model 301.

Table 3. A partial list of the effluents processed in Brinecells®.¹¹

Contaminant	Control (mg/L)	Time (minutes)	Results (mg/L)	Removal (%)
Phenols	26,000	60	20	99.92
Toluene	4.79	20	0.2	95.82
Chloroform	12.17	15	2.01	83.48
Carbon tetrachloride	12.65	15	0	100.00
Pentachlorophenol	20.0	3	0	100.00
Lindane	500	30	0	100.00
TKN	23.24	60	8.25	64.50
Ammonia	201	60	0.35	99.83
Cyanide	5,400	60	1,340	75.19
Dursban	420	60	0	100.00
BOD ^a	2,240	60	480	78.57
BOD	3,500	60	850	75.71
BOD	4,200	60	225	94.64
BOD	27,100	60	185	99.32
BOD	8,980	45	1,470	83.63
BOD	20,000	45	410	97.95
BOD	20,000	45	102	99.49
COD	3,270	60	754	76.94
COD	10,000	60	3,880	61.20
COD	20,550	180	4,295	79.10
COD	233,000	60	141,700	39.18
COD	16,980	60	8,800	48.17
COD	2,410	45	185	92.32

a. Biochemical oxygen demand.

2. PROCEDURES

The Brinecell® Model 301 was leased from Brinecell® Inc. of Salt Lake City, Utah, and shipped to the EG&G Idaho Pilot Facility at Kelly AFB, San Antonio, Texas. The electrolytic cell for the Model 301 is 7 × 20 in. and cylindrical. The power supply has an input of 220 Vac and an output of 10 Vdc 100 amps, 1 kW. Included with the Model 301 was a 50-gal tank and a submersible mixing pump. It is estimated that the pump was capable of circulating the liquid at approximately 20 gpm. Figure 1 shows the system set up.

The 90-L mark for the tank was determined by calculating the tank volume and height required to hold 90 L. For each test, water was added to just below the 90-L mark, the desired weight of salt (Morton or Culligan water softener salt (99.5 and 99.6% sodium chloride, respectively) was added, the spent stripper solution was added, and the liquid level was brought to the 90-L mark. Initial testing was conducted starting with the solution temperature at room temperature. The submersible recirculation pump was used for the mixing. During testing, the cell was laid on its side in the solution instead of standing on end as shown in Figure 1. This was required due to the volume of water used during testing. This is the method shown in some of the literature from Brinecell®, Inc. Since the salt is slow going into solution, it was necessary to mix up the solution the evening before the test. When the solution was mixed in this manner, the stripper was not added until just before the test started. The solution was brought to the 90-L mark after adding the stripper.

Operation of the submersible pump during the test duration resulted in an increase in the solution temperature from 23°C to as high as 44°C. To control the temperature, a Neptune Model L mixer was used for mixing. To increase and control the temperature, a Metro Corporation, Sethco Division Fused Quartz Model 1000G Thermersion Heater was used. When heating the solution, the heater was set to the desired temperature the evening before the test so that the solution would be at temperature by the start of the test.

Two hundred milliliters of the sample was collected for each analysis. The samples were analyzed for color using the HACH DR 3000 Spectrophotometer and the HACH method for true and apparent color. The stored program is calibrated in color units based on the APHA-recommended standard of 1 color unit being equal to 1 mg/L platinum as chloroplatinate ion. The maximum color that can be read with this method is 550 units, therefore, the samples of a higher concentration were diluted with dionized water. Apparent color was determined by reading the sample directly. True color was determined by reading a sample filtered through a filter that will not pass 1 µm or greater. In addition, color was determined for the sample after filtering through a 0.45 µm filter.

The pH of the samples were determined with a portable Corning Model 107 pH meter calibrated with a 7 and 10 buffer. The pH was determined after color determination on the sample. This allowed the sample to return to near room temperature.

Chloride was determined using the HACH DR 3000 Spectrophotometer and HACH Mercuric Thiocyanate Method. Due to the high chloride concentration, the sample was diluted 1 to 5,000 to be well within the maximum concentration range of 20 mg/L Cl⁻.

Figure 1. Brinecell® Model 301 treatment unit.

COD was analyzed using the HACH Reactor Digestion Method and the HACH prepared digestion vials. Due to the high chloride in the samples and the interference of the chloride with the colorimetric method, the samples were diluted and additional mercuric sulfate was added. With this procedure the sample is digested two hours. The oxidizable organic compounds react, reducing the dichromate ion ($\text{Cr}_2\text{O}_7^{2-}$) to the green chromic ion (Cr^{+3}). The reagent is in a sulfuric acid solution. Due to the peroxide and ozone in the samples during the operation of the Brinecell, the COD of the samples could not be determined during the operation of the Brinecell. The chromate was immediately reduced upon the addition of the sample. Sodium bisulfite is a recommended chemical for the removal of the peroxide; however, it also reduces the chromate. Therefore, COD could only be analyzed after the sample had set for at least 1 day.

The Total Carbon and Total Organic Carbon for the sample was determined using a Dorhman Carbon Analyzer and the method provided with the instrument. Since chloride interferes with carbon analysis at concentrations of greater than 2%, the sample was diluted 1 to 10 before injection. The organic carbon was determined by first purging 100 mL of the sample for 30 minutes after the addition of 1 mL of phosphoric acid. Since the instrument was not working well during the time of analysis, the calibration provided with the instrument was not used. The concentration was calculated by determining the peak height of 200 and 400 mg/L carbon, a range where the calibration curve is linear, and calculating the concentration using the equation for the line and peak height of the sample.

Nickel was determined using the HACH 1-(2-Pyridylazo)-2-Naphthol (PAN) method for nickel. Since the samples were not digested before analysis, the total recoverable nickel was not determined.

3. RESULTS

The Brinecell®'s application to the treatment of the red-water causing noncyanide strippers was evaluated as a function of stripper concentration, solution pH, sodium chloride (salt) concentration, and temperature. Spent Clepo 204-T Noncyanide Stripper, manufactured by Frederick Gumm Chemical Company was the primary stripper on which the Brinecell® and process parameters were evaluated. This stripper was selected because the operations personnel at Building 301 had this stripper ready for disposal. The treatment of the Metalx B-9, manufactured by Metalx, Inc. was evaluated after setting the processing parameters for the Clepo 204-T. The results of the evaluations are discussed below. The results of the testing are tabulated in Appendix A.

3.1 Clepo 204-T

The stripper concentration was evaluated to determine the concentration that could be treated with the Model 301 Brinecell® in a manner permitting evaluation of the maximum number of parameters during the time the equipment was leased. Completing the treatment in an 8 to 10-hour test period allowed monitoring of the color removal as a function of time and comparison of the effect of the different parameters. The stripper concentration was evaluated at dilutions of 1 to 20, 1 to 200, 1 to 300, and 1 to 400 (dilution by volume).

At the 1 to 20 dilution the initial salt concentration was 2 g/L. This was increased as shown in Figure 2, as the test progressed, since significant reductions in the color were not seen (Figure 3). Additionally, the pH was decreased, as shown in Figure 4, to increase the reaction rate, as recommended by the manufacturer.¹¹ This test was operated for 60 hours. The apparent color increased during the test period from 7,900 to 36,400 units. The true color initially increased from 7,900 to 20,400 units before decreasing to 9,700 units after approximately 30 hours of treatment. This corresponded with reduction of the pH to 4.7 and increasing the salt concentration to 60 g/L. However, further operations at these conditions did not significantly decrease the color. During the testing, significant precipitate formation occurred as can be seen in the difference in the true and apparent color (see Figure 3).

Brinecell® treatment of a 1 to 200 dilution of the Clepo 204-T at pH 4.4 with 20 g/L salt resulted in a reduction in the True color from 1,380 to 425 units as shown in Figure 5. During testing the true color increased from 1,380 to 2,050 units before decreasing, while the apparent color increased from 1,625 to 2,645 units. During this test, the solution pH was not controlled except with the adjustment of the initial pH to 4.4 units. The pH decreased as shown in Figure 6, from 4.4 to 2.5 units by the end of the test. Following testing, the pH of a 1 L sample of the treated solution was adjusted to pH 10 with caustic to precipitate the heavy metals. Heavy metal precipitation did not occur at pH 10. However, an intense red color developed as the pH was increased above pH 8. Increasing the pH to 12 resulted in metal precipitation. At this pH, the true color was 3,800 color units. This indicates the color removal during testing was not totally due to treatment with the Brinecell® but was also due to the decrease in the pH caused by the acid formation during treatment.

Brinecell® treatment of the Clepo 204-T at a dilution of 1 to 300 with 20 g/L salt and the pH unadjusted resulted in an initial increase in the true color from 785 to 1,415 units with a final true color of 865 units after 720 minutes of treatment (see Figure 7).

Figure 2. The increased salt concentration for the Brinecell® test with a 1 to 20 dilution of the Clepo 204-T.

Figure 3. The change in color of the Clepo 204-T solution at a 1 to 20 dilution as a function of the treatment time with the Brinecell®.

Figure 4. The pH adjustment as a function of test duration for the treatment of Clepo 204-T at a 1 to 20 dilution.

Figure 5. The color remaining as a function of test duration when treating a 1 to 200 dilution of Clepo 204-T at an initial pH of 4.4 and 20 g/L salt with the Brinecell®.

Figure 6. The change in pH during treatment of a 1 to 200 dilution of Clepo 204-T at an initial pH of 4.4 and 20 g/L salt.

Figure 7. The color remaining as a function of test duration when treating a 1 to 300 dilution of Clepo 204-T at an initial pH of 8.6 and 20 g/L salt with the Brinecell®.

Brinecell® treatment of a 1 to 400 dilution of the Clepo 204-T with 35 g/L salt is shown in Figure 8. The true color increased from an initial color of 391 units to 736 units before starting to decrease after 60 minutes of treatment. The final color of the solution was 62 units after 8 hours of treatment. The adjustment of the pH of this solution to 12 did not result in any change in the color, nor did aeration of the sample for 24 hours.

Initial testing was conducted without temperature control. The submersible pump provided with the Brinecell® treatment unit was used to circulate the solutions. The pump generated heat with operation, thereby increasing the temperature of the solution as the test duration increased. In addition, as the temperature of the solution increased, the system current increased. This is illustrated in Figure 9. It was also noted that increased color removal occurred as the temperature approached 40°C. The temperature was, therefore, controlled with a quartz immersion heater, and the solution was mixed with an electric mixer. The temperature was controlled in this manner for all but the first six tests.

Temperature was further evaluated using a 1 to 400 dilution of the Clepo 204-T with the addition of 60 g/L salt at 40 and 50°C. The results of these tests are shown in Figures 10 and 11. As can be seen by comparing the two graphs, the maximum apparent color determined at 50°C (744 units) was much lower than that obtained at 40°C (902 units). In addition, the apparent color remained lower during the 50°C test. The true color was decreased to 8 units with the temperature at 50°C after 530 minutes of operation, while the true color was decreased to 23 units at 40°C operation.

The effect of decreasing the salt concentration to 50 g/L while operating at 50°C is shown in Figure 12. Comparison of Figure 12 with Figure 10 above, shows that both the true and apparent color remained higher throughout the test duration when treating with 50 g/L salt instead of 60 g/L. The optimum salt concentration was, therefore, selected as 60 g/L while 50°C was selected as the optimum temperature for the treatment of the Clepo 204-T with the Model 301 Brinecell®.

During treatment of the Clepo 204-T with 60 g/L salt at 50°C, the pH decreased as shown in Figure 13. The effect of controlling the pH of the solution at a pH greater than 8 was evaluated (Figure 14). There was little difference in the true or apparent color for this test than for the test shown in Figure 10. However, in operation, the hydrochloric acid odor becomes much stronger as the pH approaches and becomes less than pH 7.

Figure 15 shows the remaining total carbon, total organic carbon, and COD when treating a 1 to 400 dilution of the Clepo 204-T at the optimum conditions of 50°C, 60 g/L salt, and without controlling the pH. The final COD was 170 mg/L, while the Total Carbon was 207 mg/L and the Total Organic Carbon was 21 mg/L. Figure 16 shows the nickel remaining in solution for the same test. Since the samples were not digested before analysis, the total recoverable nickel was not determined. However, the figure indicates the reduction of nickel concentrations for the filtered solution when treated with the Brinecell®.

Figure 8. The color remaining as a function of test duration when treating a 1 to 400 dilution of Clepo 204-T at an initial pH of 8.6 and 35 g/L salt with the Brinecell®.

Figure 9. The change in temperature and current as a function of the test duration when recirculating with the submersion pump.

Figure 10. The color remaining as a function of test duration when treating a 1 to 400 dilution of Clepo 204-T at an initial pH of 8.6, 60 g/L salt, and 50°C.

Figure 11. The color remaining as a function of test duration when treating a 1 to 400 dilution of Clepo 204-T at an initial pH of 8.6, 60 g/L salt, and 40°C.

Figure 12. The color remaining as a function of test duration when treating a 1 to 400 dilution of Clepo 204-T at an initial pH of 8.6, 50 g/L salt, and 50°C.

Figure 13. The change in the solution pH as a function of the test duration when treating a 1 to 400 dilution of the Clepo 204-T at 50°C and 60 g/L salt.

Figure 14. The color remaining when treating a 1 to 400 dilution of the Clepo 204-T at 50°C and 60 g/L salt while controlling the pH greater than 8.

Figure 15. The organic carbon, total carbon, and COD remaining when treating a 1 to 400 dilution of the Clepo 204 T with the Brinecell® at 60 g/L salt and 50°C.

Figure 16. The nickel remaining when treating a 1 to 400 dilution of the Clepo 204 T with the Brinecell® at 60 g/L salt and 50°C.

Increased operation of the Brinecell® results in a carbonate build up on the cell. The cell was cleaned with concentrated hydrochloric acid, as recommended by the manufacturer.^a Cleaning only required immersion of the cell in the acid for 1 to 2 minutes. Additionally, when the cell was allowed to operate an additional 5 hours to see if the color could be decreased to less than 8, a black precipitate formed in the solution. The manufacturer reports this to be carbon/carbonates from reaction with the cell. The black precipitate could be dissolved with gas evolution when the pH was lowered to less than 4.

3.2 Metalx B-9

A sample of spent Metalx B-9 was treated at a 1 to 400 dilution at the optimum conditions found for the Clepo 204-T (i.e., 60 g/L salt and 50°C). The results of this test is shown in Figure 17. The initial apparent color increased from 140 to 470 units within the first 30 minutes of the test as the solution color changed from yellow to a rust orange color. The true color during this period was similar to the apparent color. After 5 hours of testing the true color was 60 units. However, after 2 hours of testing, a black precipitate formed in the solution, and the apparent color increased as shown in Figure 17. Continued operation did not further decrease the true color.

The Metalx B-9 contains a high concentration of carbonates as sodium carbonate. A second test was conducted using a sample of the Metalx that had been acidified to pH 4, removing a part of the carbonates. This sample was treated at 50°C after adjusting the solution pH to 8 with caustic. The salt concentration was increased to 80 g/L. The test results are shown in Figure 18. The black precipitate formed as in the previous test. To remove the carbonates, the pH was adjusted to 6

a. Telephone conversation with Mr. Tim Themy, Brinecell® Inc., Salt Lake City, Utah, May 23, 1994.

Figure 17. The color change of a 1 to 400 dilution of Metalx B-9 treated at 50°C and 60 g/L salt.

Figure 18. The color change of a 1 to 400 dilution of Metalx B-9 treated at 50°C and 80 g/L salt after acidifying the stripper to remove carbonates.

and then to 4 with sulfuric acid. The pH adjustment resulted in a significant amount of off-gassing as can be seen when dissolving carbonates. Additionally, the solution began to clear. However, at the lower pH, a strong concentration of hydrochloric acid odor was noted. To alleviate the hydrochloric acid off-gassing, the pH was readjusted to pH 6. The true color of the solution was 60 units after 5 hours of treatment. A sample of the final solution was adjusted to pH 10 with caustic. The final true color was 60 units. The Total Carbon, Total Organic Carbon, and COD were 509, 75, and 90 mg/L, respectively.

4. CONCLUSIONS

The application of the Brinecell® process for treatment of the noncyanide strippers for color removal was evaluated as a function of stripper concentration, temperature, salt concentration, and pH for the Clepo 204-T. In addition, the process was evaluated for treating the Metax B-9 stripper. The Brinecell® Model 301 removed the color to 8 units for a 1 to 400 dilution of the Clepo 204-T stripper and to 60 units for the Metax B-9 stripper. The conclusions drawn from the test were

- Increased temperatures are required to treat the noncyanide strippers for color removal. The optimum temperature for treatment was 50°C. Operating at this temperature, while increasing the color removal, does not pose an operational problem or safety hazard as it is below the temperature where scalding can occur.
- Sixty grams per liter of salt, or currents at 40 amps were required to treat the 1 to 400 dilution of the sample in an 8-hour period.
- Operating at pHs below 6 did not enhance the color removal. Operation at these pHs, however, resulted in increased hydrochloric acid formation and off-gassing. In addition, the color would decrease due to the decreased pH but would return even more intensely when the pH was adjusted to 8 or greater.
- The color increases during the initial treatment with the Brinecell® process. It is believed this is caused by completing the oxidation of the color forming compounds. After the initial increase in color, there is a steady decrease in the color of the solution.
- Brinecell® treatment of the sample resulted in a 72% reduction in the COD of the sample and a 85% reduction in the total organic carbon. Additionally, 90% of the nickel was removed.
- Carbonates present in the stripper and formed during the Brinecell® treatment slowed the color removal process. To fully treat the stripper for color removal, a method of removing the carbonate prior to treatment and during treatment needs to be incorporated into the process. This could be accomplished with acidification, filtration, and/or precipitation of the carbonates.
- As the Brinecell® is operated, carbonates build up on the cell. Cleaning of the cell with hydrochloric acid is required during operation.
- As the Brinecell® is operated, a strong chlorine odor develops, similar to that found with a jacuzzi. Sufficient ventilation or closed loop operation of the unit would be required on the full scale.
- Precipitates are formed during the Brinecell® treatment of the strippers. Incorporation of a filtering system in the treatment would significantly reduce the metal loading to the Industrial Wastewater Treatment Plant.

A 1 to 400 dilution of the stripper was required to treat the stripper in an 8-hour period. This is not indicative of the concentration of the stripper, which could be treated full scale. For full-scale treatment, the unit would be sized incorporating the stripper concentration, time available to treat the stripper, and type of treatment operation desired (i.e., batch or continuous). The Brinecell[®] process can be operated by recirculating a stream of the stripper through the cell with saline injection (batch process) or on a continuous basis. The volume and concentration of the waste determines the size of the electrolytic cell.

5. RECOMMENDATIONS

The current cost of stripper disposal as a hazardous waste is estimated at \$150,000/year. Currently disposal of the stripper may take as long as 2 months. Point source treatment of the stripper would eliminate this long disposal time. Additionally, Brinecell® treatment of the stripper would eliminate the disposal cost and have low operating cost because the primary chemical for the treatment is salt.

It is recommended that

- A Brinecell® system be procured and installed for full-scale treatment of the noncyanide stripper wastewaters.
- The system would be sized to meet production requirements, and additional tests performed to size the carbonate removal and filtration systems.
- The system controls and maintenance requirements be incorporated.
- Implementation of the Brinecell® system would include installation, training of personnel, and an operation and maintenance manual.

6. REFERENCES

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Appendix A
Brinecell® Test Data

Appendix A

Brinecell® Test Data

Brinecell® Test # 1

Date: May 9, 1994
 Stripper: Clepo 204
 Stripper concentration: Diluted 1 to 400 with tap water
 Temperature: Uncontrolled
 Salt concentration: 24 g/L NaCl
 pH: Uncontrolled.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 μ m) (unit)	True color (0.45 μ m) (unit)	Temperature (°C)	Current (amp)
0	8.6	377			23	
30	8.9	518		451		
60	9.0	522		439	27	14
90	8.9	475		390	27	14
150	8.4	418		298	32	15
210	7.9	352		207	35	16
270	7.7	227		107	36	16
330	7.7	150		56	38	17
390		96		25	41	18

a. Initial test to check out the system operation. Salt was not weighed out but was added to achieve a current reading. The stripper solution was added after the salt addition, and the cell was operational.

Brinecell• Test # 2

Date: May 10, 1994
 Stripper: Clepo 204
 Stripper concentration: Diluted 1 to 20 with tap water
 Temperature: Uncontrolled
 Salt concentration: Started at 2 g/L NaCl, incremented to 60 g/L by test end
 pH: Initial pH was adjusted to 7.5 with sulfuric acid. During the testing, the pH was lowered with sulfuric acid as indicated.

Duration (min)	pH (unit)	Apparent color (unit)	True color (0.45 μ m) (unit)	Temperature (°C)	Current (amp)	Chloride (mg/L)	Sodium chloride (mg/L)
0	7.5	7900	7900	24	4	1722	2854
10	7.5	7000	7100		4	1812	3003
25	7.5	7600	6600	24	4	1812	3003
40	7.5	7500	6800	24	4	1825	3024
60	7.6	7600	7700	26	4	1812	3003
90	7.6	9100	8900	26	4	1890	3132
120	7.7	9900	9100	28	5	1828	3029
150	7.7	9800	8900	28	5		0
180	7.7	9400	9400	29	5	1746	2893
210	7.7	9900	9900	30	7	2990	4955
270	7.8	10400	10400	32	7	1610	2668
330	7.9	12500	11000	34	10	5000	8286
390	7.9	11500	10500	35	10	6850	11351
450	8.0	11000	11000	37	14	10640	17632
510	6.4	14100	11700	40	16	8660	14351
570	6.5	13200		39	21	9595	15900

a. Initial salt concentration was low, the salt concentration was increased as indicated below:

120 minutes: Added an additional 180 g salt.
 270 minutes: Added an additional 360 g salt.
 390 minutes: Added an additional 500 g salt.
 510 minutes: Adjusted pH to 5.7, added an additional 500 g salt.

b. At 570 minutes, the system was set to operate an additional 5 hours.

Brinecell® Test # 2
Continuation of Previous Day Test

Date: May 11, 1994
Stripper: Clepo 204
Stripper concentration: Diluted 1 to 20 with tap water
Temperature: Uncontrolled
Salt concentration: Started at 2 g/L NaCl, incremented to 60 g/L by test end
pH: Initial pH was adjusted to 7.5 with sulfuric acid. During the testing, the pH was lowered with sulfuric acid as indicated.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	Temperature (°C)	Current (amp)	Chloride (mg/L)	Sodium chloride (mg/L)
0	6.6	17400	17000	29	17	14230	23581
60	6.7	19500	17200	29	29		
120	6.7	19400		32	32	29875	49507
180	6.4	19500	18400	35	35	31725	52572
240	6.4	20700	20200	36	36	34675	57461
300	4.7	26900	9700	39	39	36475	60444
360	4.4	27800	8800	38	38	36975	61273
420	4.4	32700	7700	38	38	32000	53029
480	4.4	29200	8000	39	39		
540	4.4	36400	8200	40	40	38175	63261

a. Continuation of the previous day run. Time zero represents the first sample taken after the 5-hour run time plus 9 hours of no operation.

b. Additional salt was added, and the pH adjusted as shown below:

0 minutes: Added 1,000 g additional salt.
60 minutes: Added 1,000 g additional salt.
200 minutes: Added 1,000 g additional salt.
260 minutes: Adjusted the pH to 4.2 with sulfuric acid.

c. At 340 minutes, a gel-like precipitate formed in the solution. The precipitate was slow to settle, possibly due to the temperature. However, settling did occur with time.

Brinecell® Test # 3

Date: May 12, 1994
Stripper: Clepo 204
Stripper concentration: Diluted 1 to 200 with tap water
Temperature: Uncontrolled
Salt concentration: 10 g/L NaCl
pH: Initial pH was adjusted to 4 with sulfuric acid. The pH was controlled at 4 with caustic.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 μ m) (unit)	Temperature (°C)	Current (amp)	Chloride (mg/L)	Sodium chloride (mg/L)
0	4.2	1420	1315	23	8	5463	9053
30	4.4	1710	1550	24	8	5990	9926
60	4.4	1820	1600	28	8		
90	4.3	1915	1735	28	8	5620	9313
120	4.3	1845	1700	28	8	5480	9081
150	4.2	2015	1740	28	8	6010	9959
180	4.1	2245	1755	28	10	5950	9860
240	3.9	2385	1925	33	10	5950	9860
300	4.2	2415	1915	36	10		
360	4.2	2450	1925	36	10		
420	4.0	2240	1885	38	10		
480	3.9	2300	1720	38	10		
540	4.1	2215	1750	40	11		
600	4.3	2440	1820	40	11		
1140	3.4	1500	975	44	7		

a. At 600 minutes, the cell was set for an additional operation of 9 hours. The data at 1,140 minutes represent the 9 hours of operation plus approximately 5 hours of no operation.

Brinecell® Test # 4

Date: May 13, 1994
 Stripper: Clepo 204
 Stripper concentration: Diluted 1 to 200 with tap water
 Temperature: Uncontrolled
 Salt concentration: 22 g/L NaCl
 pH: The initial pH was adjusted to 4 with sulfuric acid. Following initial adjustment the pH was not controlled.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	Temperature (°C)	Current (amp)	Chloride (mg/L)	Sodium chloride (mg/L)
0	4.4	1625	1380	27	14	14180	23498
30	4.3	1935	1760	28	14		
60	4.2	2100	1890	31	15	14080	23333
120	4.1	2615	2090	34	17		
180	4.0	2645	2050	35	17	13980	23167
240	3.9	2350	1835	37	17		
300	3.8	2325	1840	39	18	15400	25520
360	3.7	1955	1385	40	18	11780	19521
420	3.7	1750	1300	41	19	11160	18494
480	3.7	1900	1500	42	19		
540	3.4	1780	1205	42	19	11000	18229
790	2.8	805	545	27	16	12810	21228
1040	2.5	535	425	32	18	11320	18759

a. At 540 minutes the cell was set for an additional 5 hours of operation. The sample at 790 minutes represents this operation plus an additional 11 hours of no operation.

b. A 1-L sample of the solution was collected at 1,040 minutes. The pH of the solution was adjusted to pH 10 with caustic. Metal precipitation did not occur at this pH. The solution, however, turned an intense red color. Adjusting the pH to 12 did result in metal precipitation.

Brinecell® Test # 5

Date: May 15, 1994
Stripper: Clepo 204
Stripper concentration: Diluted 1 to 300 with tap water
Temperature: Uncontrolled
Salt concentration: 20 g/L NaCl
pH: Uncontrolled.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	Temperature (°C)	Current (amp)	Chloride (mg/L)	Sodium chloride (mg/L)
0	8.6	800	785	23	13	11160	18494
240	8.1	1460	1415	27	14	13320	22073
420	7.3	1265	1175	33	15	10870	18013
720	7.6	1145	865	23			

a. Pumped the solution during this run. Pump added a bit of heat, therefore, the cell operation near room temperature was tried. It appeared the heat was needed to obtain good color removal.

Brinecell® Test # 6

Date: May 16, 1994
 Stripper: Clepo 204
 Stripper concentration: Diluted 1 to 400 with tap water
 Temperature: Uncontrolled
 Salt concentration: 35 g/L NaCl
 pH: Uncontrolled.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	Temperature (°C)	Current (amp)	Chloride (mg/L)	Sodium chloride (mg/L)
0	8.6	460	391	33	20	20680	34270
30	8.6	835	670	33	20	21280	35264
60	8.3	936	736	34	20		
90	8.1	766	638	35	21		
120	7.7	754	524	36	22		
150	7.3	690	546	37	22		
180	7.0	640	478	40	22		
240	7.0	566	327	44	23	22100	36623
300	6.8	440	199	44	24		
360	6.8	317	145	45	24		
420	6.8	236	73	46	24		
480	6.9	209	62	48	24		

- Precipitate starts forming at about 6 hours of operation.
- Collected sample after shut down and adjusted the pH to 11.3, the red color did not form.

Brinecell• Test # 7

Date: May 17, 1994
Stripper: Clepo 204
Stripper concentration: Diluted 1 to 400 with tap water
Temperature: 50°C
Salt concentration: 60 g/L NaCl
pH: The pH was maintained greater than 7 with caustic.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	True color (0.45 µm) (unit)	Temperature (°C)	Current (amps)
0	8.6	468	406	404	48	36
30	8.7	744	660	650	49	37
60	8.4	702	614	610	50	38
90	7.9	654	506	480	50	38
120	7.0	541	402	365	50	38
150	7.5	481	301	352	50	38
180	7.2	408	173	158	50	38
360	7.2	143	44		50	37
530	7.8	129	16	8	50	38

a. Saved 1 L of the final solution. Blue green precipitate forms. Colored of the settled sample is 16 units.

Brinecell• Test # 8

Date: May 18, 1994
 Stripper: Clepo 204
 Stripper concentration: Diluted 1 to 400 with tap water
 Temperature: 40°C
 Salt concentration: 63 g/L NaCl
 pH: The pH was maintained greater than 7 with caustic.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 μ m) (unit)	True color (0.45 μ m) (unit)	Temperature (°C)	Current (amp)
0	8.7	472	446	440	41	37
30	8.6	902	804	760	41.5	37
60	8.5	754	670	602	42	37
90	7.6	722	578	546	42	37
120	7.1	694	516	440	42	36
150	7.3	650	395	302	42	35
180	7.2	608	338	218	43	35
240	7.2	416	107	87	43	35
300	7.6	281	82	57	43	35
345	8.1	228	58	51	43	35
460	7.8	173	23	12	42	36
520	7.9	172	34	23	42	36

Brinecell• Test # 9

Date: May 19, 1994
Stripper: Clepo 204
Stripper concentration: Diluted 1 to 400 with tap water
Temperature: 50°C
Salt concentration: 50 g/L NaCl
pH: The pH was maintained greater than 7 with caustic.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	True color (0.45 µm) (unit)	Temperature (°C)	Current (amp)
0	8.7	452	426	396	50	35
30	8.6	730	654	626	50	34
60	8.4	680	608	550	50	34
90	7.8	648	592	514	50	34
120	7.2	648	534	383	52	34
150	7.3	524	324	283	51	33
180	7.8	485	262	208	51	33
240	7.2	326	113	100	50	33
300	7.2	201	91	58	49	32
360	7.7	184	59	45	50	33
420	7.6	142	39	27	50	33
480	8.0	156	37	35	53	33
540	8.0	154	37	35	53	37

a. Saved 1 L of the sample, the settled sample had an apparent color of 29 units the next morning. Filtering the sample through 0.45 µm filter reduced the color to 12 units.

Brinecell® Test # 10

Date: May 20, 1994
Stripper: Clepo 204
Stripper concentration: Diluted 1 to 400 with tap water
Temperature: 50°C
Salt concentration: 62 g/L NaCl
pH: Solution pH controlled to greater than pH 8 with caustic.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	True color (0.45 µm) (unit)	Temperature (°C)	Current (amp)
0	8.7	446	436	406	47	38
30	8.7	752	680	668	48	36
60	8.4	654	586	538	49	36
90	8.2	600	535	481	50	36
120	8.2	578	440	398	51	37
150	8.2	537	326	263	51	37
180	8.0	470	183	160	51	37
240	7.9	300	106	75	49	37
300	8.4	244	96	58	50	37
360	8.3	213	54	34	50	35
420	8.4	191	43	25	50	37
480	8.6	175	18	16	50	38
540	8.4	164	24	20	50	38

a. Set the cell to run an additional 5 hours. The solution was black the next morning due to precipitate formation. The color through a 0.45 µm filter was 50 units.

Brinecell® Test # 11

Date: May 23, 1994
Stripper: Metalk B-9
Stripper concentration: Diluted 1 to 400 with tap water
Temperature: 50°C
Salt concentration: 61 g/L NaCl
pH: Uncontrolled.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	True color (0.45 µm) (unit)	Temperature (°C)	Current (amp)
0	9.1	163	153	130	46	40
30	8.3	588	514	469	47	40
60	7.4	238	234	217	50	41
90	8.3	164	138	135	50	44
120	8.2	138	119	95	50	43
150	8.2	130	102	92	50	43
180	8.3	134	94	85	49	43
240	8.3	175	93	92	50	42

a. Black precipitate formation was noted at 180 minutes. At 240 minutes, the solution was a black color. Shut the test down and called the Brinecell® manufacturer. The manufacturer said the black color was due to carbon/carbonate formation and recommended cleaning the cell in a concentrated solution of hydrochloric acid if carbonates was building up on the cell. Carbonates could be seen when scraping the cell with a spatula. The cell was cleaned and rinsed.

Brinecell® Test # 12

Date: May 24, 1994
Stripper: Metalx B-9
Stripper concentration: Diluted 1 to 400 with tap water
Temperature: 50°C
Salt concentration: 61 g/L NaCl
pH: No control.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	True color (0.45 µm) (unit)	Temperature (°C)	Current (amp)
0	9.0	141	138	132	50	44
30	8.3	470	418	410	49	42
60	7.6	180	170	164	50	42
90	7.8	115	110	108	51	45
120	8.0	109	99	91	50	44
150	8.1	116	88	76	50	44
180	8.1	190	85	77	50	44
240	8.2	220	88	77	50	44
300	8.2	221	75	65	52	45
360	8.2	226	70	60	51	45
420	8.2	230	70	60	51	45

a. Black precipitate formation was noted at 180 minutes. Filtering through a 0.2 µm filter resulted in a color of 60 units. The turbidity of the solutions comparable to the apparent and two true colors are 27, 11, and 10 FTU, respectively.

Brinecell® Test # 13

Date: May 25, 1994
Stripper: Clepo 204-T
Stripper concentration: Diluted 1 to 400 with tap water
Temperature: 50°C
Salt concentration: 61 g/L NaCl
pH: pH controlled above pH 7.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	True color (0.45 µm) (unit)	Temperature (°C)	Current (amp)
0	8.8	464	430	406	50	41
30	8.6	780	764	690	50	41
60	8.1	728	644	610	50	41
90	7.4	645	562	526	51	39
120	6.9	505	427	367	51	39
150	7.4	456	332	278	50	39
180	7.2	337	193	158	50	39
240	7.2	185	123	89	50	40
300	7.3	120	72	55	48	40
360	7.3	111	58	40	50	40
420	7.8	101	57	28	49	37
480	7.7	228	53	25	51	39

a. Formation of the dark carbonate precipitate was noted at 420 minutes. A sample of the solution was collected at 480 minutes, and the pH was adjusted to 10.3 to 11 to precipitate the metals. The true color of this solution was 18 units.

Brinecell® Test # 14

Date: May 26, 1994
Stripper: Metabx B-9
Stripper concentration: Diluted 1 to 400 with tap water
Temperature: 50°C
Salt concentration: 80 g/L NaCl
pH: The pH of the sample was adjusted to 4 before dilution and allowed to stand for open for 2 days. After the dilution, the pH of the solution was adjusted to 8.4 with caustic.

Duration (min)	pH (unit)	Apparent color (unit)	True color (1 µm) (unit)	True color (0.45 µm) (unit)	Temperature (°C)	Current (amp)
0	8.4	150	140	137	50	42
30	8.3	481	473	418	50	49
60	7.9	168	163	155	50	51
90	8.0	113	107	94	50	53
120	8.1	110	97	76	50	52
150	8.2	273	73	68	48	51
180	6.6	265	85	70	49	50
240	5.5	249	82	62		49
300	5.7	230	68	58	49	50
360	6.2	147	84	55	51	51
420	6.2	144	73	51	51	51
480	6.3	160	74	60	50	49

a. Black precipitate formation was noted within 3 hours of starting the test. The pH was adjusted as follows:

180 minutes: Adjusted the pH to 6.0 with sulfuric acid.
 210 minutes: Adjusted the pH to 4.3 with sulfuric acid.
 240 minutes: Adjusted the pH to 4.0 with sulfuric acid.
 270 minutes: Adjusted the pH to 4.0 with sulfuric acid, it was 5.7.
 300 minutes: Adjusted the pH to just below 3.8 with sulfuric acid. The solution clears, but a large amount of hydrochloric acid is generated.
 At this time, readjusted the pH to 4.0 with caustic, however, still generating HCl.
 320 minutes: Adjusted the pH to 5.6 with caustic, which lowered the HCl odor significantly.

b. A sample of the final solution was adjusted to pH 10 with caustic. The final true color was 60 units. The Total Carbon, Total Organic Carbon, and COD were 509, 75, and 90 mg/L, respectively.