Maj or process changes have occurred in the last few years as advanced semiconductor device technology has narrowed interconnect line widths to 45 nanometers (nm). These include 300-millimeter (mm) wafer platforms and the use of copper as the interconnect conductor. Earlier interconnect technology used aluminum and tungsten conductors for multilevel metal interconnects.

As a result of these advances, the semiconductor industry must now treat wastewater from various processes associated with the use of copper. Classical technologies, such as precipitation and electrowinning, provide an acceptable treatment method for most waste streams. However, precipitation technology generates copper hydroxide sludge, which is most often classified as a hazardous waste that must be hauled to a permitted facility for disposal, or to an off-site recycler for recovery. While electrowinning is viable for concentrated waste streams, such as electropolishing and etching solutions, it is less useful and not economical when the copper concentration is less than or equal to 100 to 200 parts per million (ppm). Additionally, electrowinning is more difficult when suspended solids are present.

A supplier has developed a number of different methods for treating copper-laden chemical-mechanical planarization (CMP) wastewater. These include precipitation/clarification, removal of CMP solids by microfiltration followed by copper removal by regenerative ion exchange (IX) or precipitation, and the patented copper-removal technology (1, 2). This article discusses the development and application of copper selective resins and activated carbon processes in treating CMP wastewaters.

Wastewater Description

Most copper CMP wastewaters have similar chemical characteristics, as presented in Table A. The concentration ranges shown in Table A are typical of those found at the wastewater lift station, or the bulk collection tank, following equalization. The higher end of the range is typical where CMP tools use diversion valves to recycle and minimize water consumption.

Most wastewaters are characterized by total suspended solids (TSS) and total dissolved solids (TDS); however, newer slurry formulations contain slurry particles measured in the nanometer range. The standard test method for TSS in water and wastewater involves filtering a sample through a 0.45-micron (µm) absolute filter. TSS is determined by the dried weight difference of the filter before and after sample filtration. Particles retained by the filter are defined as TSS, while particles that pass through the filter are considered to be dissolved and contribute to TDS. The 0.45-µm filter fails to adequately differentiate total solids from dissolved solids in copper CMP slurries because a significant portion of the undissolved solids passes directly through the filter. Filters with smaller pores (e.g., 0.20 or 0.10 µm) can be used with reference to the filter size when reporting TSS results. However, even these smaller pore filters are inadequate in most cases and make classical TSS analysis impractical for copper CMP slurry wastewater.

For purposes of this presentation, total solids (TS) is used, measuring both TSS and TDS. This test is conducted by drying a measured volume of wastewater slurry in an oven at 103 to 110°C and calculating the weight difference. Copper CMP slurry wastewaters contain temperature-sensitive organic components that are readily decomposed at the oven temperature used to dry filters. Therefore, precautions must be taken to avoid burning these organic compounds and skewing the test results.

Copper Removal Technology

The copper-removal technology treats raw slurry wastewater by removing dissolved copper without the need to remove slurry solids or add chemicals, other than for pH adjustment. The pH is...
adjusted for two reasons—to ensure that all the copper in the waste slurry is dissolved, and to maximize copper removal by the IX resin. Hydrogen peroxide is removed after pH adjustment by activated carbon. Activated carbon catalytically decomposes hydrogen peroxide to water and oxygen and is both effective and efficient in reducing wastewater peroxide concentration to an acceptable level for IX. The oxygen produced by peroxide decomposition is vented to atmosphere.

After peroxide decomposition, the copper solution with slurry solids passes through copper-selective IX resin where dissolved copper is removed. The solids do not significantly foul the IX resin. When the resin is loaded with copper, the tank is replaced with one containing fresh IX resin and the spent tank is sent for regeneration offsite by a specialized regeneration technique. Copper-selective resin can be used in various configurations, for example, as a point-of-use treatment (POU) system in the facility sub-fab area to treat a small number of tools. Alternatively, it may be placed in the central utilities building (CUB) to treat an entire line of copper CMP tools. Systems can be readily configured to treat 3 to 500 gallons per minute (gpm) of CMP wastewater. Higher flowrates can be accommodated if needed. The process is robust and applicable to most copper CMP slurry chemistries.

The patented copper-removal technology has been previously described. It was the subject of a Sematech-funded study of copper CMP wastewater at a Motorola site (2). This and other studies show the copper-select process is effective in removing copper with little or no retention of CMP particles. It has been demonstrated that copper in the tested slurry wastewater is dissolved and not chemically or physically bound to the slurry particles. Similar verification has also been reported in a copper CMP slurry treatment process using microfiltration and diafiltration (3).

A supply company initiated a long-term laboratory study to investigate copper-removal technology performance with chemical additives typically found in CMP slurry formulation. Among the tests were:

- The effect of solution pH on copper-loading capacity of the IX resin;
- The effect of pH on copper loading in the presence of organic chelators;
- The solubility of copper and copper chelates as a function of pH;
- The effect of surfactants and wetting agents;
- The effect of slurry composition on hydrogen peroxide destruction efficiency; and
- The effect of hydrogen peroxide on IX resin capacity.
IX Resin Capacity as a Function of Solution pH

It is well known that the operational capacity of IX resin is directly related to solution pH. The goal of this test was to maximize copper loading on IX resin while minimizing precipitation of copper and copper chelates. Initial studies of the copper select process indicated that copper would start to precipitate from CMP wastewater when pH was in the range of 6.2 to 7.4, the expected pH range for precipitation of dissolved copper (1).

Tests were conducted using a synthetic CMP slurry wastewater of typical composition described in Table A, except that slurry solids were excluded. The synthetic wastewater contained citric acid and an aryl triazole, each in concentrations of about 100 milligrams per liter (mg/L). Citric acid is a common chelating agent used to complex copper dissolved during CMP processing and prevent it from precipitating or depositing on the wafer surface. Alkyl and aryl triazoles are anti-tarnish compounds that prevent oxidation of freshly etched copper surfaces. For this test, copper concentration of the synthetic solution was approximately 40 mg/L. Sulfuric acid and sodium hydroxide were used to adjust solution pH to the test condition. Ion-exchange resin was conditioned, rinsed, and placed into IX columns and the synthetic CMP slurry wastewater was pumped through the resin columns at an empty bed contact time (EBCT) of 3 minutes. At a pH of 1.5, the resin copper-loading capacity at breakthrough was 0.6 pounds per cubic foot (lb/ft³), while at a pH of 3.0, it was 2.52 lb/ft³. The resin capacity at breakthrough was 2.80 lb/ft³ when the pH was 3.5.

The results clearly show that the copper-removal process is best when the solution is more alkaline than at pH 1.5. Below this pH level, competition between copper and hydrogen ions for the resin exchange site favors hydrogen ion and the resin is essentially regenerated. As acidity decreases (pH increases), copper loading improves, as shown by comparing copper loading at pH 3.5 compared to pH 3.0. Although not shown in the data described above, IX resins with chelating functionality of the type tested show little further improvement in copper capacity as the pH becomes more alkaline to the point where copper precipitation begins (approximate pH 6.2).

In practice, a pH of about 4.0 is consistent with maximum copper loading. Adding sodium hydroxide to raise the pH above 4.0 provides no practical payoff in terms of the amount of copper loaded. Likewise, if the ambient pH of copper CMP slurry wastewater is higher than 4.0, adding acid to reduce it to 4.0 insignificantly affects copper loading, as long as all of the copper in the wastewater is dissolved. Further tests show that other components in copper CMP slurry wastewater make it important to control influent to a lower pH for effective copper-removal treatment.

Copper and Copper Chelate Precipitation as a Function of pH

Copper triazole complex forms at the CMP tool and precipitates from solution immediately downstream from the CMP tool (4). In the wastewater treatment system, this precipitated copper accumulates at the top of the activated carbon and IX resin beds, giving rise to an increase in the differential pressure across the tanks. At some point, continued accumulation of the precipitate will plug the beds and flow through the tanks will stop. Partially plugged tanks will channel wastewater through the beds and lead to the early appearance of copper in the effluent due to bypassing the IX resin or insufficient contact time with the resin. Channeling through the carbon bed allows excessive hydrogen peroxide to enter the IX tanks, leading to resin deterioration, reduced copper loading and early resin replacement. This will be discussed in more detail later.

For this test, synthetic copper CMP wastewater solutions were prepared using 500 mg/L of an aryl triazole and 100 mg/L of copper ion (as copper sulfate) at an initial pH of 2.0. Sodium hydroxide solution was used to increase the pH of the test solutions in 0.5 pH unit increments. They were covered and allowed to stand undisturbed for about 15 hours after which each was analyzed for copper and the aryl triazole remaining in solution. Results are shown in Table B. In another test, 500 milliliters (mL) of solution containing 200-mg/L copper (as copper sulfate) was prepared...

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Figure 5. Ion-exchange capacity in the presence of surfactants.

Figure 6. Carbon breakthrough of surfactants.
bined with 500 mL of a solution containing 1,000 mg/L aryl triazoles. Both individual solutions were adjusted to pH 4.0 with dilute sodium hydroxide or sulfuric acid solutions.

After mixing, the combined solution had a pH of 3.26 and immediately turned olive green in color. This color intensified as sodium hydroxide was added to adjust solution pH. The most intense green color was observed at pH 3.45. When acid was added to the combined solution, color diminished until, at pH 2.7, the green color disappeared entirely, leaving a light blue copper solution. Copper forms a complex with aryl triazoles, which is responsible for the color observed in this test. When acid is added to the solution, the triazole is protonated by the hydrogen ion. Copper is decomplexed and returns to solution as the simple cupric ion. As this test indicates the copper aryl triazole complex begins to form at pH 2.7, and is essentially fully formed at about pH 3.5.

Concentrations of residual aryl triazole and copper were measured by ultraviolet (UV) absorption and inductively coupled plasma-mass spectrometry (ICP-MS), respectively. In the region of pH 2.5 to 3.0, about 60% of the copper in solution precipitates as the copper-aryl triazoles complex. As alkalinity (pH) increases, so does complex formation. At pH 4.0, about 95% of the copper precipitates as the aryl triazole complex within 15 hours and increases to 100% after 48 hours. In a published report, the copper aryl triazole complex was shown to have a 1:1 ratio of copper to triazole (5). That report was based on an examination of aryl triazole bound to zero valent copper metal surfaces. The result of the present study indicates that the complex has a 1:2 triazole-to-copper ratio when copper is present in solution as the cupric (Cu^{2+}) ion.

The complexation test was repeated, this time adding 500 mg/L citric acid to the synthetic solutions. The results are presented in Table C. As previously stated, citric acid is a common additive to copper CMP slurry formulations and is a copper chelating agent. The log of the formation constants for copper citrate, CuL1 and CuL2, are K1 = 4.35, and K2 = 14.2, respectively (6). In the presence of citric acid, no precipitation of copper-aryl triazole complex occurred at any pH tested level. This was evidenced by the lack of formation of the purple/blue solid copper triazole complex reported in Table B.

While the tests reported in Tables B and C looked at citric acid and aryl triazoles only, the results show that copper precipitation is a genuine concern for the system operator. Whether or not precipitation occurs depends on the relative concentrations of chelator and antitarnish components in the wastewater and the operating pH. For the copper-select process, these results coupled with the information regarding copper loading on IX resin, show that operation needs to be conducted at a pH that is acidic enough to avoid copper precipitation, but not so acidic that the hydrogen ion successfully competes with cupric ion for the IX sites on the IX resin. Further, the results demonstrate the importance of testing chelating and other compounds likely to be present in slurry wastewater prior to implementing changes to the copper CMP composition on the tools. This is explored further in the next section.

**Effect of Chelating Compounds on the Copper-Removal Technology**

A baseline test solution containing no chelating compounds was initially tested to allow for process comparison. Copper was added as the sulfate salt to give 40 mg/L of copper in the test solution. Baseline results showing copper concentration plotted versus the empty bed volume (EBV) are shown in Figure 1. It is typical to see reduced overall metal loading capacity when small IX columns are used for testing because of column wall effects and lack of good liquid distribution to the top of the IX resin in the column, among other factors. Therefore, while the results of such tests are useful for the purpose of direct comparison under the same test conditions, they cannot be safely extrapolated to full-scale systems.

Ion exchange breakthrough for these experiments was defined as 35 mg/L of copper, 85-90% of the influent concentration. Breakthrough is typically de-
fined as some point between 50% and 100% of the influent concentration from the lead column when ion exchange systems are operated in a “lead/lag” two-column configuration and depends on the user’s desired safety margin. For the baseline test, breakthrough was established at about 2,000 EBV.

Additional tests were run using the same IX column apparatus, except that chelating compounds were added the test solution to determine their effect on resin loading. The chelating compounds tested were oxygen and nitrogen-based, composed of organic hydroxy-acids, α, δ-dicarboxylic acids, amines, diamines and amine/oxygen-based chelates. Examples are oxalic acid and ethylenediaminetetraacetic acid (EDTA). Each test solution was prepared by adding enough chelating compound to give 170 mg/L. This concentration is significantly higher (greater than 10 times) than that found in most CMP wastewaters; however, testing at this concentration ensured that the effect on metal loading would be readily apparent during a short-term column test. The results for these tests are given in Figure 2. As shown, good correlation exists between the conditional formation constant of the copper chelate and the volume of test solution treated to the breakthrough point.

The formation constant, $K_f$, is defined by the following equation and indicates the strength of the metal to chelate chemical bond as illustrated in Equation 1.

$$\text{Cu} + n\text{Chelator} \leftrightarrow \text{Cu(Chelate)}_n$$

Eq. 1

The strength of the chelate bond depends on pH, and the conditional formation constant, $K_f$, is the formation constant calculated at a specific pH. The types of chelating compounds evaluated for this study form weaker chelates with copper as the test solution becomes more acidic, that is as the pH drops. This is because the chelating compound prefers the acid, or protonated form, under increasingly acidic conditions. When the acid concentration is strong enough, the chelating compound is completely protonated and will not bind with metal. For example, citric acid will not form a chelate with copper at a pH below about 2.7, but binds copper most strongly at about pH 6. Ethylenediaminetetraacetic acid will not bind copper below about pH 2 and is strongest about pH 11.

These results demonstrate that CMP slurry formulation and operational pH of the system effect how well the copper-removal technology takes out from the slurry wastewater. It is evident from Figure 2 that some chelating compounds prevent sorption of copper on the IX resin. Incorporation of these compounds must be avoided in copper CMP slurry formulations whether copper removal is accomplished by IX or traditional precipitation processes. Other chelating compounds appear to have little, if any, effects on the ability of the IX resin to remove copper from copper CMP wastewater. This highlights the importance of knowing and testing possible slurry formulations before implementing them on the copper CMP tools.

Chelating compounds were also tested for their effect on activated carbon. Organic compounds load on activated carbon at a rate dependent on their concentration and water solubility, among other factors. Organic loading is related to the loss of catalytic activity, as will be shown later. The same test solutions used to evaluate the effect of chelating compounds on IX resin copper loading were used for the carbon tests. Ion exchange columns were set up in the same manner as the ion exchange tests except that activated carbon was placed in the test columns. Total organic carbon (TOC) concentration was used to determine breakthrough of each chelating compound. Results are shown in Figure 3. Note that the test solutions were prepared using an equal mass of each compound so the solutions have different initial TOC concentrations. Aryl triazole was used in the baseline solution for this set of tests. In each case, TOC breakthrough for chelating compounds occurred earlier than for the baseline solution. This is observed by examining the inflection point in the chart in Figure 3 for each compound tested.

These results show that the copper chelates tested are less strongly adsorbed on carbon than aryl triazoles. Though none of the compounds tested had breakthrough later than aryl triazole, such a result would indicate that the compound was more strongly adsorbed by activated carbon than the aryl triazole.

The next tests examined whether these compounds affect the efficiency of the activated carbon decomposition of hydrogen peroxide in copper CMP slurry wastewater. Chelating compounds were added to a solution containing copper and hydrogen peroxide and the breakthrough point of the hydrogen peroxide was monitored. Results of these tests are shown in Figure 4. Malonic, glutaric, and pimelic acids are a family of α, δ-dicarboxylic acids that differ only in the number of –CH2– units between the terminal carboxylic acid groups. Both malonic and pimelic acids show peroxide breakthrough at about the same point.

Given the similarity in molecular structure, glutaric acid would be expected to breakthrough at about the same point as the other dicarboxylic acids tested; however, the test was stopped prior to this point. The size of the glutaric acid molecule is intermediate between malonic and pimelic acid. The citric acid test was stopped at 1,000 bed volumes (BV) when it was found that citric acid, a hydroxy tricarboxylic acid, was being removed from the test solution by its reaction with hydrogen peroxide. Later tests showed that addition of aryl triazole to the test solution prevented the reaction between citric acid and hydrogen peroxide. We presume that this protective effect is because of the formation of the copper aryl triazole complex discussed previously, or perhaps a complex between copper, aryl triazole, and citric acid. In any event, the addition of triazole interferes with the reaction of citric acid and hydrogen peroxide.

It is important to reemphasize that small column tests results cannot be extrapolated to full-scale systems. Typical carbon bed life ranges from 12,000 to 20,000 BV in full-scale systems. The range is, of course, dependent upon additives in the solution, and environmental conditions.

**Effect of Surfactants on Copper-Removal Process**

These tests explored the impact of surfactants on activated carbon and IX resin and were conducted in a similar manner as the chelating reagent study already described. A baseline solution was used, consisting of copper, aryl triazole, and the test surfactant. The surfactants tested were representative of various chemical families used in copper CMP slurry formulations. Tested surfactants included disodium lauramphodiacetate (DLD), lauramidopropyl betaine (LMB), polyethylene glycol (PG), and polyoxyethylene lauryl ether.
The results in Figure 5 show the bed volumes of test solution treated to breakthrough. For these tests, breakthrough was considered to be the point at which the effluent copper concentration reaches 30 mg/L.

LBM shows a constant bleed of copper beginning around 160 EBV. The other surfactants had no detrimental effect on the ability of the IX resin to remove copper from the test solution compared to the baseline solution. Unexpectedly, it appears that some surfactants may improve resin capacity for copper. However, no follow-up tests were conducted to explore this observation.

A study was initiated to examine how surfactants affect activated carbon. Effluent TOC was used to determine surfactant breakthrough. As shown in Figure 6, surfactants composed of smaller molecules, such as ethylene glycol (EG), breakthrough more quickly than the baseline aryl triazole solution, while larger molecules, such as POELE, breakthrough later. These results are expected based on the octanol/water partition coefficient values for these molecules. The octanol/water partition coefficient is used to predict adsorption of organic molecules on hydrophobic media such as activated carbon.

Next, the effect of surfactants on the efficiency of activated carbon decomposition of hydrogen peroxide was investigated. Figure 7 shows effluent hydrogen peroxide plotted versus the bed volumes of treated test solution. Test solutions that contained copper, hydrogen peroxide, and surfactant, were prepared and tested as previously described. No direct correlation was evident between surfactant breakthrough (as TOC) and loss of hydrogen peroxide decomposition efficiency by the activated carbon. Likewise, no apparent correlation was observed between the octanol/water partition coefficient and surfactant mass loading on the carbon.

However, as is generally known, increased organic loading on the activated carbon decreases its ability to decompose hydrogen peroxide. Therefore, CMP slurry wastewater with higher levels of organic compounds known to adsorb onto activated carbon will more rapidly reduce its hydrogen peroxide decomposition efficiency. Operating parameters such as pH play an important role in how rapidly organic loading occurs. As already demonstrated, water solubility of the organic compounds is strongly affected by wastewater pH. Wastewater testing provides valuable insight into how well a specific CMP slurry formulation will respond to different operating conditions and should precede process changes on the tools.

**Hydrogen Peroxide Effect on IX**

The copper-removal treatment process uses activated carbon to decompose hydrogen peroxide present in the copper CMP wastewater before it enters the IX resin tank. It is well known that oxidizers, like hydrogen peroxide, react with functional groups, and divinyl benzene cross links on the IX resin. Oxidized functional groups are no longer able to remove metal from wastewater, which presents itself as loss of operational capacity. Oxidation of cross links eventually softens the IX resin by cleavage of the chemical bonds that hold strands of polystyrene together. The benzylic sites are particularly prone to reaction with oxidizers. At a certain point of oxidation, resin integrity is compromised. Eventually the resin softens to the point that it is unusable.

Since copper CMP slurry may contain high concentrations of hydrogen peroxide as shown in Table A, tests were conducted to measure the relationship between hydrogen peroxide concentration and the rate at which the IX resin loses its copper-loading capacity. At no point during these tests was softening of the resin observed. This confirms discussions with resin manufacturers that hydrogen peroxide reacts with the function group, not the divinyl cross links. Test solutions were made by adding electronic grade, concentrated hydrogen peroxide to deionized water at concentrations between 0 to 1,000 mg/L. Copper sulfate pentahydrate was added to these solutions to 40 mg/L as cupric ion (Cu^{+2}) and the pH adjusted to 3.0 with sulfuric acid.

At a pH between 2 and 3, a Fenton's reagent is formed. Cupric ions catalyze formation of the peroxide-free radical, which is a much more powerful oxidizer than peroxide itself. This test solution was passed through columns of IX resin until a copper breakthrough at 35 mg/L after which the resin was regenerated and the cycle repeated. Copper capacity of the IX resin exposed to each level of hydrogen peroxide was measured at intervals. A total of 13 loading/regeneration cycles were completed over a period of about 3,400 hours of continuous exposure at each peroxide concentration. Figure 8 shows the number of hours of hydrogen peroxide exposure is required to reduce the “new” resin copper capacity to 75% as a function of peroxide concentration. The data show rapid and fairly linear capacity loss between 50 and 500 mg/L of peroxide, slowing at higher concentration. This is attributed to loss of the most readily accessible exchange sites on the resin during early exposure to the oxidizer. Later, the oxidizer must penetrate deeper into the resin bead to react with remaining exchange sites; therefore, resin kinetics play a larger role at higher peroxide concentration and/or longer exposure times.

This resin oxidation study underscores the importance of ensuring removal of most of the hydrogen peroxide in order to prolong the operational life of expensive IX resins. Removal of peroxide may be done chemically by addition of a reducing agent such as sodium bisulfite; however, use of activated carbon is simpler. A simple titration for hydrogen peroxide is all that is needed to monitor the carbon, with replacement as needed. Chemical treatment involves frequent monitoring (automatic or manual) to constantly adjust chemical dose rates to fluctuating hydrogen peroxide concentrations. As found during the Semetch study, oxygen reduction potential (ORP) does not adequately measure hydrogen peroxide concentration in copper CMP wastewater so it is easy to over or undershoot reducing agent addition. Activated carbon does not need to adjust to fluctuations in peroxide concentration since it reacts with peroxide by catalytic decomposition.

**Conclusions**

Studies completed on the copper-removal technology, using typical CMP chemistry, show it to be a very robust copper CMP wastewater treatment method. Control of wastewater pH prior to activated carbon and IX resin is a key factor for successful operation and is the single most important factor in copper loading on the resin. These tests have shown copper aryl triazole complex precipitates if the solution does not contain a sufficiently strong, sufficiently concentrated chelating compound, especially at elevated pH. Evaluation of the effect of chelating compounds shows that the conditional formation constant, which can be calculated from the published literature, is useful in predicting.
TABLE A
Copper CMP Wastewater Characteristics

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration Range (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved copper</td>
<td>5-100</td>
</tr>
<tr>
<td>Hydrogen peroxide (H₂O₂)</td>
<td>50-1000</td>
</tr>
<tr>
<td>Total solids</td>
<td>500-5000</td>
</tr>
<tr>
<td>Organic chelators</td>
<td>10-50</td>
</tr>
<tr>
<td>Total organic carbon</td>
<td>10-100</td>
</tr>
<tr>
<td>Alkyl or aryl triazoles</td>
<td>50-200</td>
</tr>
</tbody>
</table>

TABLE B
Test with Synthetic Copper CMP Solutions

| Test Condition Cu⁺ Triazole Appearance |
|----------------------------------------|--------------------------------------|
| pH 2.0                                 | Cu⁺ 102 mg/L, Triazole 530 mg/L       |
|                                        | colorless solution                    |
| pH 2.5                                 | Cu⁺ 100 mg/L, Triazole 530 mg/L       |
|                                        | colorless solution                    |
| pH 3.0                                 | Cu⁺ 41.3 mg/L, Triazole 260 mg/L      |
|                                        | purple/blue solids, green solution    |
| pH 3.5                                 | Cu⁺ 22.1 mg/L, Triazole 195 mg/L      |
|                                        | purple/blue solids, green solution    |
| pH 4.0                                 | Cu⁺ 5.1 mg/L, Triazole 151 mg/L       |
|                                        | purple/blue solids, green solution    |

TABLE C
Complexation Test Results

| Test Condition Cu⁺ Triazole Appearance |
|----------------------------------------|--------------------------------------|
| pH 2.0                                 | Cu⁺ 102 mg/L, Citric 535 mg/L        |
|                                        | colorless solution                    |
| pH 2.5                                 | Cu⁺ 104 mg/L, Citric 530 mg/L        |
|                                        | colorless solution                    |
| pH 3.0                                 | Cu⁺ 102 mg/L, Citric 530 mg/L        |
|                                        | light sky blue solution               |
| pH 3.5                                 | Cu⁺ 103 mg/L, Citric 525 mg/L        |
|                                        | bright sky blue solution              |
| pH 4.0                                 | Cu⁺ 102 mg/L, Citric 520 mg/L        |
|                                        | greenish blue solution                |

the operational metal loading capacity of the IX resin.

Chelating compounds produced no observable detrimental effects on the IX resin or activated carbon at the concentrations tested. Most surfactants tested had no negative effect on IX resin metal-loading capacity and a few appeared to slightly enhance metal loading. Tests of surfactants with activated carbon provided insufficient data to demonstrate whether or not there was a correlation between the octanol/water coefficient and hydrogen peroxide decomposition. In general, organic loading on activated carbon is consistent with reduced peroxide decomposition efficiency. Finally, long-term exposure of the IX resin to hydrogen peroxide has a negative effect on operating capacity that is precluded by pretreatment with activated carbon.

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The authors would like to acknowledge Mr. J. Day, USFilter Recovery Services Inc., who conducted most of the laboratory tests for this study.

References

Endnote
aUSFilter is the supplier referred to in the text. bCopper Select™ is a patented treatment approach developed by Siemens Water Technologies that removes the copper prior to particle flocculation and precipitation. In the article, this process is referred to as the “copper-removal technology”. The Copper Select™ process removes copper from copper CMP wastewater without the need to remove CMP solids present in the water. Copper-free wastewater still bearing the CMP solids could be then sent to a classical precipitation system for flocculation and coagulation of the solids remaining.

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