

3-D Electrolytic Cell Provides New Option for Wastewater Recycle & Waste Minimization

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The cell design of a patented electrolytic technology, commercialized in 1999, allows effective use of three-dimensional porous cathodes to remove and recover metals. The cell's 3-D porous cathode has greater than 500 times more effective surface area than a 2-D electrode of the same nominal size. This high surface area allows metal deposition at higher current efficiencies, lower current densities and higher deposition rates, and thereby achieves lower final metal ion concentrations. This advanced technology has demonstrated the following: the capability to achieve metal discharge limits without further treatment; the collection of these metals as elements ready for sale or reuse; the use of removable cartridges for ease of operations and maintenance; and the reduction of life cycle costs. While this technology can be applied in a variety of ways, ranging from process water treatment to metal recovery to effluent treatment, the potential of water recycle and waste minimization is being realized today. For example, the cell is being placed at point sources of copper and other metal releases, including metal plating drag-out and rinse tanks. Instead of these waters being released to waste treatment, the cell recovers the metal at the sources and allows the rinsewater to be used longer, thereby reducing water consumption and discharges, all at a substantial cost advantage over conventional technology. Several applications and experiences are presented, with a focus on heavy metals (Cd, Cu, Pb and Ni).

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Introduction

Metal ion removal and recovery are necessary in many industrial and chemical process treatments. Metals may be present as a result of corrosion of process equipment, raw material contamination, catalyst carryover or operational plating streams. Such situations represent a loss of metal, and in many cases an effluent problem, that has to be dealt with, particularly now that discharge of metals and disposal of metal sludges are much more rigorously controlled. The U.S. EPA and other national regulatory bodies are focused on heavy metals including Cd, Cr, Cu, Pb, Hg, Ni and Zn.

There is a need to address this problem in an economic manner and considerable efforts have been devoted to the development of technologies that can offer an answer, e.g., ion exchange, reverse osmosis, solvent extraction and electrolysis. The goal has been to supplant the most commonly used method of effluent treatment—chemical precipitation, with improved methods that can recover the metal in a reusable form, and hopefully solve the effluent problem in a cost-effective manner.

Unfortunately, most individual metal removal techniques used in the treatment of process and waste streams have the disadvantage of requiring other technologies to meet process and effluent limits, and/or they produce a metal-bearing secondary effluent solution or mixed solid requiring further treatment.

Of these, only electrolysis has the potential of producing a directly reusable product from a dilute effluent or process solution. However, there are two major problems in the electrolysis of dilute (i.e., <1g/L) metal ion bearing solutions:

- » The process becomes mass transport limited, therefore capital costs are often high and performance is generally poor.
- » The economic return from dilute solutions of metals is generally very small and often imposes a serious limitation to the sophistication and costs an application can afford. The exceptions to this are toxic metals and precious metals.

Electrolytic cells have been commercialized for metal recovery over the past two decades mostly as concentrators where further purification is required to obtain the metal in a directly reusable form. The most common configurations include parallel flat plate cathodes, reticulated cathodes, and high surface

area cathodes. Various cell manifestations have been developed to minimize the mass transport limits and reduce the equipment footprint and costs. Unfortunately, the performance of these conventional electrochemical cells is marginal at dilute or low metal ion concentrations. While some of these cells can be effective down to metal ion concentration levels of around 50 - 200 mg/L, effluent discharge levels are typically less than 5 mg/L and often below 1 mg/L.

Patented Technology*

Last year at this conference, a new electrolytic cell capable of removing metal to below 1 mg/L concentration was introduced. The cell design effectively uses three-dimensional (3-D) cathode materials, in most cases a porous carbon element, through the flow path and current distribution illustrated in Figure 1. The use of a 3-D cathode greatly enhances the performance of the cell since the porous carbon felt has at least a 500 times greater effective surface area than a two-dimensional (2-D) electrode of the same nominal geometric size.

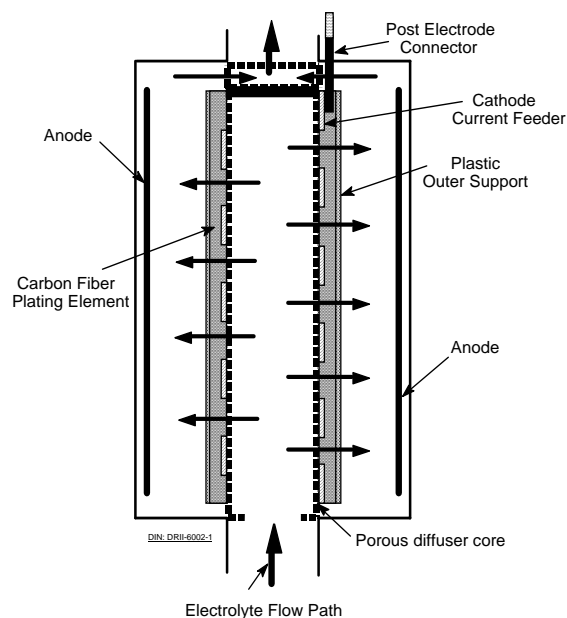


Figure 1 - Standard Cell Schematic Cross-Section

The patented design of the cell makes this very high surface area available for metal deposition at higher current efficiencies, lower current densities and higher deposition rates for a given nominal cell

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size than commercial cells with 2-D and other 3-D cathodes. The cell's large surface area is in intimate contact with the metal-bearing electrolyte and a uniform flow rate, current density, and cathode potential insure that the mass transport limits on metal concentration are reduced by nearly a factor of 1000 while maintaining much higher (and more cost effective) current efficiencies resulting in a smaller equipment footprint. The net result is that this cell can achieve lower final metal ion concentrations while using less energy to remove a given amount of metal from a metal ion bearing solution. In general, the technology is capable of two to three orders of magnitude lower final concentration of metal ions, and three to ten or more times higher current efficiency than other commercial electrochemical cells at concentrations between 50 and 5 mg/L. The current efficiency improvement is even higher between 5 and 0.1 mg/L (or even 0.01 mg/L for some applications). Such low metal concentration levels are not even possible by present commercial electrochemical cells.

A standard cell for industrial applications consists of an 0.5 m long polypropylene housing with an outside diameter of 200 mm. The area of the cathode in this device, on a 2-D basis, is approximately 0.11 m². The actual plating surface of the carbon element is at least 55 m². A larger standard cell is also available consisting of a 1.0 m long housing of the same outside diameter, and having a 2-D cathode area of 0.23 m² and 3-D area of 115 m².

Other size cells are also available in response to market needs and experience. In addition, for certain applications, a variation of the standard cell is the "divided" electrochemical cell, in which a hydroscopic membrane (normally a cation exchange membrane) is positioned concentrically between the cathode and the anode. In this case, two electrolyte solutions, anolyte and catholyte, are required. The divided cell system is applied to solutions containing species that should not be oxidized at the anode or that would interfere with the cathodic deposition process, e.g., chlorine generation from aqueous chloride solutions.

When the cathode is completely laden with metal to the point of blocking virtually all flow through the cell, the cathode must be replaced or otherwise regenerated. Similar to a cartridge filter, the spent cathode element is recovered by switching off the power supply and pumps; removing the top end plate; and extracting the metal-laden cathode cartridge assembly. A new cathode cartridge assembly is then

inserted into the cell, and the cell is ready for operation. The metal-laden cathode can then be recovered and sent to a smelter or otherwise handled.

Technology Performance

As noted, the performance of a "conventional" electrochemical cell is limited at lower metal ion concentrations as illustrated in Figure 2. These devices are usually based on metal plate or mesh cathodes in a tank combined with some means of mass transfer enhancement (e.g., moving the electrodes or achieving turbulent process flow). Thus, to reach 1 mg/L or lower, an additional treatment process, such as ion exchange, is required. This increases complexity and costs when compared to this new electrolytic technology.

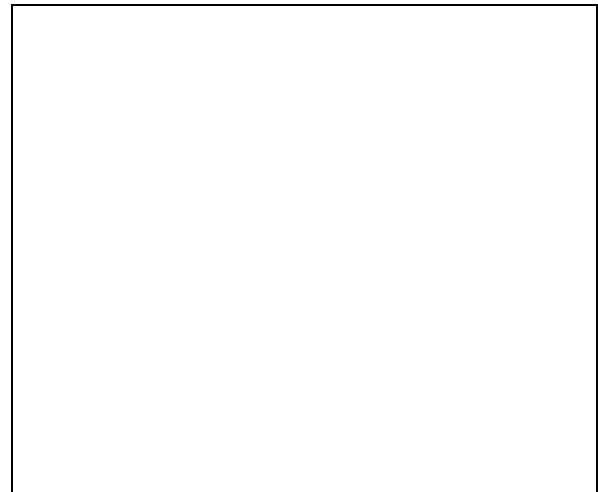


Figure 2 - Comparison with Conventional Electrolytic Cells on Copper-laden Process Solutions

The cell is based on the effective use of a 3-D cathode in metal ion removal applications. This technology has evolved over the past 12 years from 2-D planar and cylindrical cathodes and fluidized bed 3-D cells. By taking advantage of the very high surface area of carbon and other materials, the cell design has extended the metal ion (concentration) removal range two to three orders of magnitude lower than other commercial cells and can often compete directly with ion exchange and substantially outperform precipitation.

In general, if a metal can be electroprecipitated, the cell will be successful. The 3-D cathode technology has been successfully used or

demonstrated on the following metals in a variety of matrices:

Cadmium	Nickel
Copper	Cobalt
Mercury	Rhodium
Platinum	Gold
Iron	Lead
Osmium	Palladium
Ruthenium	Silver
Tin	Zinc

Other metals of possible interest include arsenic, antimony, polonium, molybdenum and tungsten that are recovered as alloys with other platable metals. While no metal electrodeposition occurs with chromium, manganese and titanium, they do electroprecipitate at the cell's cathode as oxides or hydroxides and are effectively removed. A special version of the cell is being developed to effectively

handle these metal forms. Other metal recoveries are being continually tested and evaluated.

Based on over 700 tests performed over the past seven years, the technology has demonstrated excellent removal capability of a range of heavy metals, value metals and precious metals found in numerous industries and applications in the UK and U.S.

Table 1 presents typical experience for a variety of process liquors and rinses, and effluent streams. Typical use includes plating bath maintenance, rinse bath treatment, enhancing ion exchange resin operating life, ion exchange regenerant treatment and reuse, as well as various precious metal recovery and heavy metal removal operations. In general, any potential applications should be evaluated against the cell's design features and capabilities as noted in Table 2.

**Table 1
Typical Testing and Operating Experience**

<i>Effluent</i>	<i>Metal</i>	Concentration		<i>Removal Efficiency (%)</i>
		<i>Initial (ppm)</i>	<i>Final (ppm)</i>	
Acid sulfate rinse	Cu	910	0.02	99.99+
	Cu	98.2	0.22	99.78
Cyanide plating rinse	Cu	105	0.34	99.68
Fluoborate plating rinse	Cu	115	0.3	99.74
Electroless Cu rinse	Cu	82	0.8	99.02
Micro etch bath rinse	Cu	44	0.11	99.75
Cyanide plating rinse	Ag	740	0.34	99.95
Cyanide static dragout	Cd	107	0.34	99.68
Acid sulfate rinse	Cd	978	0.37	99.96
Acid sulfate rinse	Zn	77.5	0.23	99.70
Acid sulfate rinse	Sn	93.2	0.5	99.46
Fluoborate plating rinse	Pb	85	0.32	99.62
Watt's bath rinse	Ni	105	0.5	99.52
Acid sulfate rinse	Cr(III)	124	1	99.19
Cyanide liquor	Au	380	<0.1	99.97
Acidic liquors	Pt/Pd	24/110	1/0.01	95.83/99.99
	Pt	2000	0.5	99.98
	Pd	500	<0.5	99.90
Groundwater (acidic)	Hg	6.3	0.036	99.43

**Table 2
Technology Features and Capabilities**

Features	Capabilities
Porous carbon felt cathode	Greatly increased deposition surface area High metal extraction rates Effective at concentrations down to 1 mg/L and below Three to ten times more energy efficient
Metal deposits plated on fiber	Minimizes or eliminates generation of hazardous metal sludges

Replaceable cathode cartridges	Easy metal removal Quick and easy cathode replacement Low operation and manpower requirements
Compact, robust design	Increased reliability in industrial environments Very small footprint Capable of being wall mounted
Optional divided cell design	Allows treatment of anodically-sensitive solutions
Industry-standard components	Allows for modular design

While the following discussion uses U.S. experience, statistics and regulations, it is noted that much of the industrial world has similar or more stringent regulatory environments and operational restraints.

Wastewater Recycle and Waste Minimization — Industrial Practices

Currently, metals in wastewater are removed by the addition of chemicals that precipitate the dissolved metals as metal hydroxide or sulfate in the plating and surface finishing industry. The solid particles are removed as a wet sludge by filtration or flotation and then disposed to landfill. Due to the addition of chemicals during precipitation treatment, the water generally cannot be recycled to rinse operation and consequently the treated water is discharged. In the mid-90s some 70,000 tons of Cu/Pb compounds and 230,000 tons of metals were disposed annually in the U.S., while worldwide, four to six times this quantity were disposed. The cost associated with the transport and disposal in the U.S. of Cu/Pb sludges and metal sludges were in excess of \$25M and \$65M, respectively, with additional costs associated with the liability of future landfill cleanup. According to a survey of 318 U.S. plating shops in the metal plating industry, an average of 160,000 L/day of water is discharged from a plating shop. For the entire printed wiring board industry (i.e., about 800 shops), this represents 30 billion liters/year of water discharged, and with average water and sewer costs of \$0.01/liter, this represents an additional cost of \$25M/year. In addition, the costs of sewer and water are rising at 150% and 200% of the inflation rate, respectively. The actual cost of in-shop treatment is not included in these figures. For the larger metal finishing industrial sector (over 10,000 shops), the numbers are much larger.

Available techniques for the removal of metal ions include chemical precipitation, ion exchange, evaporation, solvent extraction and a variety of membrane separation processes including reverse osmosis, ultrafiltration and electrodialysis. Each of these methods has its own advantages but all lack the ability of certain electrochemical techniques to

produce metal directly in a controlled fashion. Conventional recovery methods can provide water with low metal concentration for discharge; however, the concentrate stream generated needs further treatment and often the dilute stream needs to be polished. Conventional electrowinning is not efficient to treat low concentration of wastewater and the treated water cannot be recycled because pH is not neutralized. However, the new 3-D cell, because of its excellent performance on dilute metal bearing solutions, offers a practical alternative to the high cost of waste sludge and long-term liability risks.

Against this backdrop, it is noted that the U.S. metal finisher and PWB industries have been highly regulated and strongly encouraged to reduce waste generation and emissions. Since the passage of the Pollution Prevention Act of 1990, the emphasis has been to prevent pollution at the source followed by recycling and treatment and disposal. Thus, waste minimization at the source is a desirable goal though rarely practical with conventional technology.

General Metal Finishing

The 3-D electrodeposition technology has proven applicable to the prevalent metals, and their complexes, that abound in the metal finishing industry. These metals include nickel, copper, cadmium, zinc, lead, tin, gold, silver, palladium, and chromium. In these industrial applications, this technology focuses on waste minimization and metal recovery in the context of a complex and diverse set of issues associated with chemical-based solutions including:

- » different types and concentrations of metals, concentrates and rinses;
- » various volumes of metal contaminated liquids;
- » more stringent metal compliance levels associated with environmental regulations; and
- » increasing process and water treatment costs.

One of the higher profile industrial sectors of metal finishing is printed wiring board (PWB) and electronics manufacturing. This multi-billion dollar

industry is a large user of water and major generator of metal contaminated wastewater.

PWB Plating Operations

The conducting circuitry of a PWB contains copper as the most prevalent conductor along with the lesser use of nickel, silver, tin, tin/lead, and gold as etch resists or top-level metals. Electrodeposition technology is well proven in removing these metals from process rinse waters.

PWB manufacturing involves over 50 different process steps, many of which generate metal ion wastes. Subtractive processing involves the selective removal of copper to form the conductive circuit patterns. Initially, a photosensitive resist material is transferred to the virgin copper surface and the circuit patterns are exposed to UV light, and with the circuit pattern developed, the remaining unwanted exposed copper surface is then etched away by chemicals and rinsed by water. The image resist material is then removed and a final protective solder resist is applied.

Plated through-hole PWBs require the selective deposition of copper and tin or tin/lead on an image formed in a similar way. The plating resist forms the circuit pattern and, on its removal after plating, the etch resist (the tin or tin/lead) protects the circuit during etching of the newly exposed substrate copper. Subsequent similar processes selectively plate nickel and gold on the edge contact of the circuit.

This electrolytic cell technology focuses on the removal of metals from these complex chemistries and provides for waste minimization and continued reuse of the rinse waters and addresses the issues of:

- » increase in process and water treatment costs;
- » more stringent metal compliance levels associated with effluent regulations;
- » various volumes of, and concentrations in, metal contaminated water rinses; and
- » reclaim of valuable metals.

Two typical PWB plating lines are reviewed for identification and application of the cell as a point source treatment technique.

Pattern Plate Acid Copper and Tin/Lead Plating Line

PWB process lines include concentrated chemistries for cleaning, etching, electroplating, and stripping, each followed by rinsing process steps.

Both acid sulfate and copper pyrophosphate copper plating solutions find use today industrially. Acid sulfate solutions are the predominant copper plating solutions used in the PWB industry, although pyrophosphate solutions are specified by some military applications where ductility of the deposit is of paramount importance. Both solutions are also used in the plating-on-plastics industry after an electroless strike has been applied to the non-conductive surfaces. Acid sulfate copper solutions are also used to plate steel wire, stainless steel cooking utensils and zinc die castings (after a cyanide copper strike). Pyrophosphate solutions are often used in electroforming applications and in the plating of zinc, aluminum, and steel die castings.

Typical formulations for acid sulfate copper solutions are:

» <u>General Purpose</u>	
Copper sulfate	190 - 300 g/L
Sulfuric acid	38 - 75 g/L
Chloride ion	30 - 60 mg/L
» <u>High-Throw</u>	
Copper sulfate	60 - 90 g/L
Sulfuric acid	150 - 225 g/L
Chloride ion	30 - 60 mg/L

These plating chemistries are made up by adding the chemical constituents to deionized water. As can be seen from the difference in the formulations, high-throw solutions result from increasing the conductivity of the solution by increasing the acid/metal ratio. The purpose of the chloride ion is to promote copper anode corrosion. Proprietary additives are normally employed to level and brighten the deposit, improve the throwing power and enhance the deposit's physical properties. It is these baths and rinse waters contaminated by drag-out from these baths that require treatment.

In a typical pattern plate acid copper and tin/lead line shown in Figure 3, the PWBs are passed through a tin/lead stripper etch, an acid cleaner, microetch, and then copper plated to build up the circuit patterns, which are then further covered by plated tin or tin/lead etch resist. The electrolytic cells are placed in the process stream to treat rinse waters at the source where they can be readily reused in the process. A specific pattern plating line capable of handling 100 boards per hour is referenced for typical PWB volumes, values and other key parameters.

Conventional practice would be to have the drains and overflows from the rinse tanks go to a central treatment facility for eventual treatment by chemical precipitation and possible polishing by ion exchange. The opportunity to reduce waste generation and practice rinse water reuse is minimal in such cases since conventional treatment options cannot selectively remove metal and maintain process water specifications.

Micro-etch and Copper Plate Spray Rinse Water

In a typical process, the rinsing of the panels after micro-etch and copper plating is often performed in the same process stage, and often this is a spray rinse. The common copper concentrations of 25 g/L for micro-etch and 15 g/L for copper plate are used in this process sequence. When the rinse waters from these operations are treated with the cell, more than 1200 kg pounds of copper per year are recovered and rinse water usage is substantially reduced (90 percent or more) as are discharges to the facility's waste treatment system.

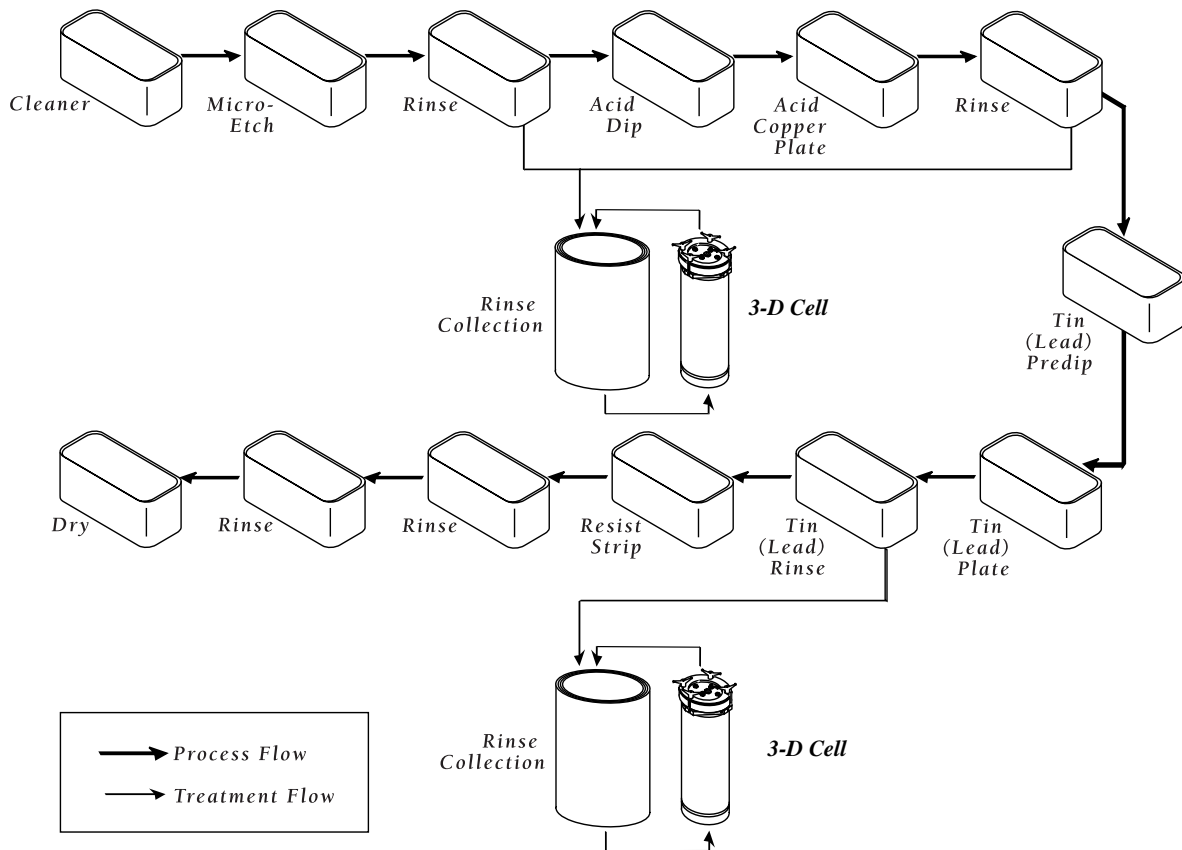


Figure 3 - Pattern Plate Acid Copper and Tin/Lead Plating Line

Tin Spray Rinse Water

Immediately after copper plating, tin/lead, as an etch resist, has been the predominant metal finish plated over the copper. Now, due to environmental concerns about lead, tin/lead is largely replaced with tin when a reflow finish is not required. Tin concentration of 14 g/L is used in this process sequence. Electrolytic treatment of rinse water after the tin plating process recovers approximately 430 kg of tin per year. Tin reclaim by refiners is enabled because tin metal is not considered hazardous in the U.S.

Waste Treatment

Copper is the only constituent of these plating solutions that is controlled by the U.S. EPA. As with most other controlled metals, the allowable discharge limits have fallen sharply in recent years. Current EPA wastewater effluent standards for existing metal finishing sources discharging to a Publicly Owned Treatment Works (POTW) for copper are 3.38 mg/L

for a single day and 2.07 mg/L monthly average. In most shops the plating solution and its associated rinses are but one of many processes that contribute copper to the waste stream. Specific requirements are controlled by local regulations and can be much more stringent; each facility must deal with local, as well as state and federal requirements. One facility discharging into surface waters in Ohio is limited to 23 µg/L as an average with a 35 µg/L daily maximum, while a Detroit facility, discharging into the city sewer system, has a pretreatment daily maximum 24-hr composite sample of 4.5 mg/L of copper. This factor of over 100 in concentration limits severely challenges the available technologies.

Treatment requirements for wastes can be fairly extensive. Routine waste treatment by pH adjustment and clarification, ion exchange, or membrane technology can prove successful in meeting these requirements. Sludge from plating shops is classified as F006 waste and is affected by the land ban legislation. Copper-bearing sludges generated by platers must be disposed of in an EPA-approved manner. Recent changes in disposal

regulations of metal-hydroxide sludges are coming into effect and require additional fixation or stabilization to prevent redissolution. Recycling of plating wastes is becoming a more viable alternative as new technology such as this enhanced electrolytic cell provides improved reclaiming processes.

Another typical PWB application is briefly addressed below.

Nickel/Gold Tab Plating Line

A typical tab connector plating line only immerses a small portion of the printed wiring board in the solution chemistries. The PWB proceeds sequentially through the tin lead stripper etch, copper electro-polish, cleaner, and micro-etch chemistries followed in line by nickel plate, gold strike and gold electroplate which completes the process. While less metal is generated in this process, the value of recovered gold and nickel significantly reduces overall process costs.

A specific nickel/gold tab line is referenced to gather typical PWB volumes, values, and other key parameters. This typical line will process 30-60

PWB panels hourly generating 72 L/hr of contaminated rinse water (see Figure 4).

Tin/Lead Strip Rinse Water

The rinse of the solder-mask-over-bare-copper surface finish method (SMOBC) has made tin/lead plating unnecessary for most panels. Lead on the panel surface is a major source of waste lead in the process fluid. Lead concentrations are typically 50 g/L and tin concentrations 50 g/L. The cell can remove approximately 150 kg each of tin and lead per year from rinse waters after the tin/lead strip sequence.

Copper Electro-polish and Micro-etch Rinse Waters

This sequence is a significant source of copper contamination in process fluids and rinses. Micro-etch strip etch copper concentrations of 25 g/L are used with this line process. The rinse water cycles after this sequence generate approximately 75 kg of copper per year.

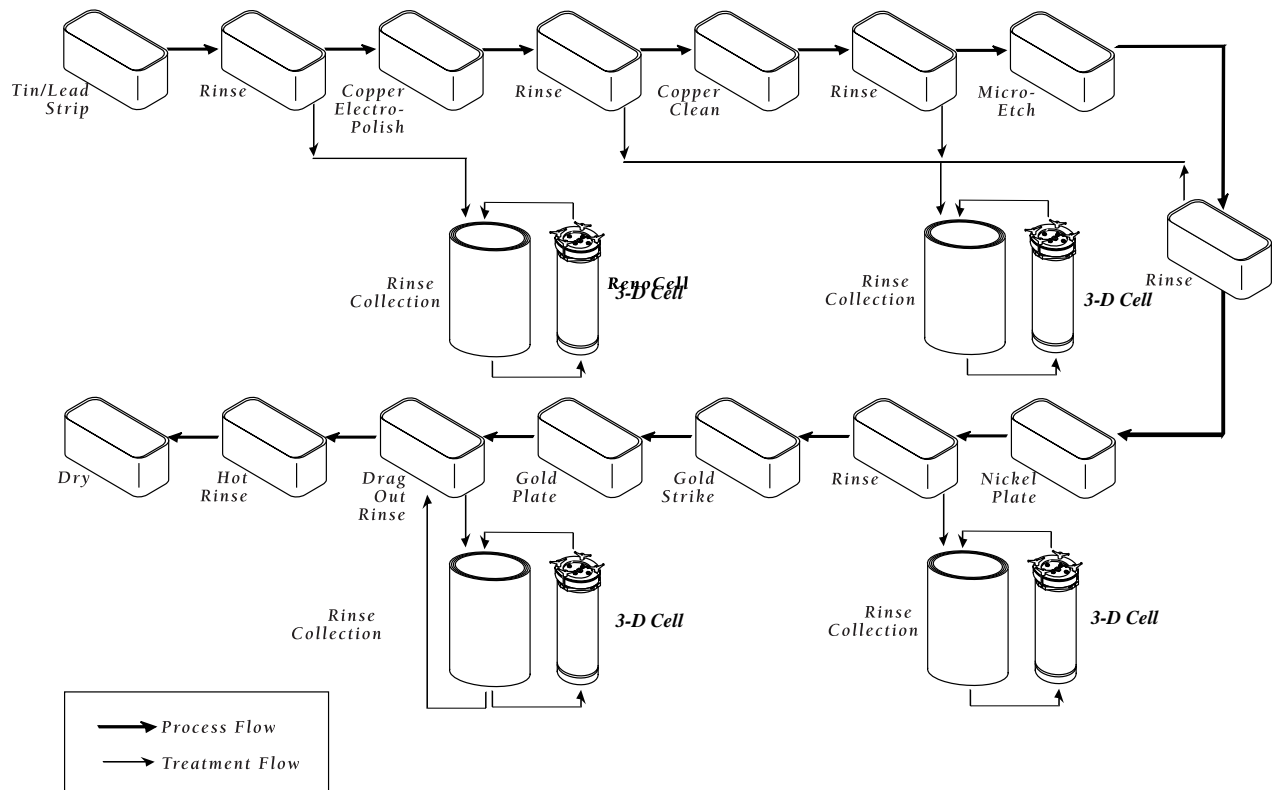


Figure 4 - Nickel/Gold Tab Plating Line

Gold Plate Drag-out Rinse Water

Nickel/gold finishes may be selectively plated onto certain areas of a circuit. The most common application of hard gold is onto edge connectors. Here, the panel is processed through a nickel/gold plating line with just the edge connector immersed in the plating fluid. Gold concentrations of 5 g/L and nickel concentrations of 50 g/L are used with these process sequences. The cell recovers approximately 15 kg of gold and 140 kg of nickel from rinse waters after the nickel/gold electrolytic strike and plate sequence.

Gold carried into the drag-out is removed, giving concentrations at discharge from the cell of 0.1 mg/L or lower. This reclaim effectively provides a major source of recovery income which helps to fund the removal of copper from other rinse sources and render tab plater discharges suitable for disposal to drain without any precipitation processes. The gold deposit on the cell's cathode cartridge is suitable for direct reclaim by precious metal specialists without the need for transfer of a hazardous liquid, containing the precious metal, between sites.

The value of the gold and nickel recovered more than offsets the cost of electrolytic treatment for the entire nickel/gold tab plating line PWB process. There is a one-year or less payback of capital equipment costs. With respect to high value metals such as gold and nickel, the value of the metal recovered more than offsets the annual operating costs attributable to the cell. The value of the gold and nickel recovered can also be applied to the capital and operating costs of utilizing source treatment in other parts of the PWB operation. When the technology is used as a source treatment, metal-bearing sludges are not generated, eliminating the costs and liabilities of handling and treating these hazardous sludges. Water usage in rinse tanks is

reduced and effluent discharge is substantially reduced as indicated in Table 3.

Acid Cadmium Barrel Plating

This metal finishing application involves cadmium removal from rinse water. The results compare the electrolytic cell to ion exchange treatment and conventional precipitation for the application of treating 75 liters per minute (108,000 L/d) of plating rinse water containing 120 mg/L Cd at 2100 μ mho and reducing the concentration to 0.7 mg/L.

**Table 3
Treatment Technologies Comparison**

<i>PWB — Pattern Plate Acid Copper</i>				
<i>Parameter</i>	<i>Precipitation (Conventional)</i>	<i>Ion Exchange</i>	<i>3-D Electrolytic Cell</i>	<i>Cell Benefit</i>
Rinse Water	9,000,000 L		900,000 L	8,100,000 L saved
Metal				
– Cu (1300 kg)	12,000 kg sludge		150 cartridges	1200 kg Cu reclaimed
– Sn (4300 kg)	4,300 kg sludge		60 cartridges	430 kg Sn reclaimed
	16,300 kg sludge to handle and dispose		210 cartridges w/recoverable metal	
<i>PWB - Nickel/Gold Tab</i>				
Rinse Water	3,000,000 L		300,000 L	2,700,000 L saved
Metal				
– Sn (150 kg)	1,500 kg sludge		20 cartridges	530 kg metal reclaimed
– Pb (150 kg)	2,250 kg sludge		20 cartridges	
– Cu (75 kg)	750 kg sludge		20 cartridges	
– Ni (140 kg)	2,100 kg sludge		25 cartridges	
– Au (15 kg)	---		2 cartridges	
	6,600 kg sludge to handle and dispose		87 cartridges w/recoverable metal	
<i>PWB – Copper Rinse Water</i>				
Operating Cost (\$/kg Cu removed)	\$50.00	\$38.00	\$18.00	\$20 - \$32/kg cost reduction
<i>Metal Finishing - Cadmium Rinse Water</i>				
Operating Cost (\$/kg Cd removed)	\$27.53	\$19.80	\$9.10	\$11 - \$18/kg cost reduction

The precipitation costs for cadmium removal was taken from an actual Cleveland, Ohio plating shop and reflects actual operating experience and cost. The operating parameters were:

- » 300 operating days per year, 24 hours per day
- » 32,400,000 liters of rinse water per year treated
- » Initial Cd concentration: 120 mg/L and final Cd concentration: 0.7 mg/L
- » 3560 kg of cadmium was removed and contained in the precipitate sludge; total Cd present and removed by ion exchange and the 3-D cell was 3865 kg. No penalty was assessed on precipitation even though it did not meet effluent discharge limits.

The overall operating cost for this and all alternatives considered was established on the same basis. The estimated operating costs for only the Cd-bearing wastewater were determined to be:

<u>Cost Element</u>	<u>Annual Costs</u>
	<u>US\$</u>
Precipitation chemical cost	62,000
Sludge handling	31,000
Labor & power	<u>5,000</u>
Total	98,000

After normalizing all parameters to the same basis, the operating cost as shown in Table 3 was \$27.53/kg of cadmium removed by conventional precipitation.

The same operating parameters used in the precipitation analysis were used for the treatment by ion exchange. The overall operating cost for this alternative was established on the same basis as precipitation and the cell except that 3865 kg of cadmium was removed and disposed. The estimated operating cost was \$19.80/kg of cadmium removed by ion exchange.

Based upon the base case identified, the operating cost of a 3-D electrolytic cell based system was \$9.10/kg of cadmium removed. This rinse water treatment case was focused on waste minimization and cost reduction and reflects an end-of-pipe plating application.

Conclusion

Plating process lines include concentrated chemistries for cleaning, etching, electroplating, and stripping each metal, followed by rinsing process

steps. The technology provides platers and PWB manufacturers with several major benefits:

- » Virtual elimination of all metal-bearing hazardous sludges, saving over 40% in overall treatment costs
- » Total operational cost savings of over 60% compared to conventional treatment methods
- » Lower initial capital costs with faster pay back periods (less than 2 years)
- » Reduced wastewater loading on existing waste treatment facilities
- » Conformance with national and local discharge compliance standards

When used as source treatment, the cells remove copper, tin and tin/lead contaminants without the PWB manufacturer having to form metal-bearing sludges. Savings in disposal costs and water reuse minimizes annual operating costs and results in less than two years of amortization of capital costs. The use of the cell further results in a reduction of both rinse water volume and removal of metal contaminants sent to end-of-pipe treatment prior to discharge. These waste minimization practices clearly allow the user additional flexibility such as expansion of operations without an increase in the waste treatment system.

In the broader metal finishing operation, the technology has application in various operations involving concentrated baths, rinse and effluent treatment. These point source uses include bath dumps, rinse maintenance and ion exchange enhancement. The potential of waste minimization is currently being realized in both new plating line installations and retrofit upgrades of existing operations.

The use of the cell is very cost effective on a life cycle basis and studies have indicated that pay back typically ranges from 9 months to 2 years depending upon the application and particular installation. As noted from the examples in Table 3, the technology has a major operating cost advantage that, when coupled with the lack of secondary waste generation and subsequent cost of handling F006 sludges, provides an exciting new application of electrolytic technology that is capable of meeting effluent discharge standards.

The principle of electrodeposition is the same for all electrochemical cells. However, simply put, this innovative 3-D electrolytic cell technology works substantially better.