Novel Cost Reduction Strategy for High Speed Acid Copper Plating

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Abstract:

As electric rates continue to climb and the price of copper metal spirals to record levels, acid copper platers are encountering unprecedented cost for deposited metal. A patented strategy has been developed that lowers the power demand 20-30% per amount of copper deposited while maintaining all the desired physical and aesthetic properties of the deposit. A real world model is used to demonstrate and quantify the savings.

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Electric rates are continuing to climb. Data from March 2006 indicates that where you live impacts what you pay, but the trend is clear. The rates are rising.

Electric Rates, Selective areas	KWH Pricing (cents)
Carolinas[1]	10
Oregon[2]	6
Minneapolis[3]	8.5
New York City[4]	15
Chicago[5]	6.5
Milwaukee[6]	8
Southern California (average)[7]	13

Electric rates, however, may be a secondary concern to the price of copper metal, which earlier this year closed for the first time ever at an excess of $4.00/lb. With the spiraling metal and energy costs, a novel solution was sought that could realize the copper plater improved economy. The result of that work was a patented system that reduces the energy demands for copper deposition. The goal of this paper is to illustrate, using a real world model, how this reduction of energy translates to dollars saved.

Any effective model is only as good as the information used to generate it. Many of the known variables include metal costs, additive costs, consumption rates, electric rates, as well as applied amperages with associated voltages. Most of these variables will err on the conservative side. For instance, the price used for copper anodes will be the bulk $4.00/lb, which does not take into account the extraneous costing for manufacture into phos/copper anode stock.

The model will generically use brightener cost of $25.00/gal and a consumption rate of 1 gallon/318,000 AHr. It is a given that additive consumption is nebulous, predicated on the current density and concentration of active ingredients. This is the actual empirically derived usage based upon production experience, which was an average of three drums a month purchased and the 52,488,000 AHr per month the test line need to run to meet the production demands.

The model will also use an electricity rate of $0.10 per kilowatt-hour. A fairly conservative cost that nearly every plater will approach or exceed in the very near future.

Acid copper plating is 100% efficient. As such, it directly follows Faraday's law, and can be used to determine the necessary parameters to achieve a 10-mil thickness minimum per square foot of plated area. Faraday's law states the number of moles of a substance produced at an electrode during electrolysis is directly proportional to the number of moles of electrons transferred at that electrode, which simply put, states that the amount of metal deposited is proportional to the current, plating time, equivalent weight of the metal and Faraday's constant:

$$\text{Metal deposited (g)} = \text{I(amps)} \times \text{T(sec)} \times \text{Equivalent Weight} / 96{,}500$$

Copper has a formula weight of 63.55 and undergoes a two-electron change during deposition, yielding an equivalent weight of 31.775. Therefore one must use 640,000 Amp•second to deposit the requisite 210.7 grams necessary to yield 10 mils of plate on one square foot of area. This is based on the following thickness equation:

$$\text{Thickness}_{cm} = \text{gm}/(\text{area}\bullet\text{density})$$

Inserting the proper known variables for copper, 210.7 grams deposited, area of 930.25 cm^2 (one square foot), and copper density of 8.9, yields a thickness of 0.0255 cm that translates to 0.010021 inches or the targeted 10.021 mils.

Armed with the necessary mass per square foot, 210.7 gm, and Amp•hr necessary to yield that mass, 178 (640,000A•s/60sm^{-1}/60mhr^{-1}), a myriad of cost analyses can be performed. The first will be what impact the cost of the brightening additive has to the copper deposition process. A standard Brightener cost of $25/gal will be compared at 2X ($50/gal), 0.5X ($12.5/gal) and 0X or no brightener if you would rather.

Brightener Cost ($)	**25**	**50**	**12.50**	**0**
Metal cost ($)	4	4	4	4
gm/Sq ft	210.7	210.7	210.7	210.7
lb/gm	0.0022	0.0022	0.0022	0.0022
Additive cost in dollars	25	50	12.5	0
A*Hr consumption/gal	318000	318000	318000	0
A*Hr to plate 10 mil*Sqft	178	178	178	178
Gallons to plate 10 mil* Sq ft	0.00056	0.00056	0.00056	0
$ Additive/10 mil* Sq ft	0.014	0.028	0.007	0
$ Metal/10 mil* Sq ft	1.854	1.854	1.854	1.854
Total cost for 10 mil* Sq ft	1.868	1.882	1.861	1.854

Steel rods, properly prepared for copper plating, were used as the cathodes for the testing. A single 8 ft rod is about 1.3 sq ft of area (5/8" * pi * 12 * 8 / 144). Therefore the chart can be translated from a costing per 10-mil square foot processed to a cost per rod simply by multiplying the cost by a factor of 1.3.

Brightener Cost ($)	**25**	**50**	**12.50**	**0**
Rod cost ($)	2.429	2.447	2.420	$2.410
% Cost of Additive	0.75	1.49	0.38	0.00
% MFG cost change	0.00	0.75	-0.37	-0.75

It is interesting to note that either doubling the cost of the brightener or eliminating the cost of the brightener has less than a 1% impact on the per rod cost when just factoring metal and brightener contributions! Because of this, the additive of choice should not be purchased based upon cost of the additive, but rather on the performance, as the cost of the additive barely impacts the cost of the final product. It is more important to produce good pieces as the real cost of the product is tied up in the copper that is deposited, not the additive used to refine it.

The less explored possible cost savings measure for acid copper is the power consumption to deposit the metal. Reiterating, acid copper plating is considered 100% efficient by convention, so plating from a system will follow Faraday's law directly. One should note that metal deposition is predicated on the time and amperage used, not the voltage used to achieve the amperage. This is important to understand, for it is fundamental to the savings generated by the subject system. Since amperage is the plating key, one only needs to understand the fundamental relationship between amperage, voltage and power to see that power savings must be realized if amperage can be maintained at a lower voltage. Power (watts) equals current (amps) times voltage (V) or $P = IV$. Therefore if the amperage remains constant (and hence same amount of material plated), but the voltage is decreased, the power must also be decreased by the same factor. A 25% decrease in the applied voltage <u>must</u> translate to 25% decrease in the power at the same amperage. Since electricity is billed as power (kilowatts), you must realize a proportionally lower electrical operating cost when the desired amperage is achieved at a lower voltage.

A patented additive (US6676823)[8] has been discovered that can in fact lower the voltage for applied amperage with no detrimental effects to either the plating solution or the deposit integrity. This additive, an organic acid, will be referred to as "Conductivity Enhancer" or CE additive.

The voltage reduction has been demonstrated on numerous production baths. For our cost savings model, a continuous strand line used for producing copper coated rods of nominal 8-foot lengths was used for generating data. In general, the line has 6 strands going through 18 cells pulling around 600 amps in each cell. There are also 3 cells that use MMO anodes to control the copper build up and these typically run at around 450 amps each. Therefore, on average, there are 72,900 amps on the plating line at any given time. Voltages were monitored, before and after Conductivity Enhancer additions, as well as against non-enhanced plating cells/solutions on other lines. The standard voltage on the line before CE additive was about 6.5 volts. This was reduced to about 4.8 volts after addition of the material. This represents essentially a 25% decrease.

The cost associated with this decrease can be quantified. The following comparisons are very representative of the effects that occur on the line.

System	Standard	Enhanced with CE Additive
Amps	72900	72900
Volts	6.5	4.8
Watts	473850	349920
Kilowatts	473.85	349.92
kW*Hr/day	11372.4	8398.08
kW*Hr rate ($)	$0.10	$0.10
Electric cost per day ($)	$1,137.24	$839.81

The system with the CE additive produces the same amount of amperage, and hence the same amount of plating, for **$297.43** a day ***less*** than the standard system. This is a savings of $**104,101.20** when projected over a year (350 days). This can be quantified any number of ways. When considering that the line uses 1,749,600 AHr per day, the savings represent:

$0.000170 saved per AHr
or
$0.030 saved per 10 mil/Sq ft deposited
or
$0.039 saved per rod
or
$0.039 saved per 274 gm of copper deposited
or
$0.065 saved per pound of copper deposited

There is a cost associated with incorporation of the CE additive. If the CE additive has an associated cost of $20.00/gal, it would cost $18,000.00 to charge the 9000 gallons of test solution (900 gallons x $20/gal). The breakeven point for the initial cost is 60.5 operational days. After the 60 days, the customer realizes all the savings. The material is not consumed by electrolysis and factoring in a very generous replenishment schedule for dragout of a drum a month still realizes a net gain of over $70,000.00 in electrical savings over the first year, and even more in subsequent years.

If one wishes to further quantify the model, it can be shown that the electrical cost is about $0.15 per rod for the standard system and reduces to $0.11 per rod when the CE additive is present. The per rod cost for the CE additive replenishment is only $0.005, leaving a net savings of $0.035 per rod produced.

As a cross check, standard output from the line was determined based on both line speed as well as a "Faradic" predication. Theory dictates that if the line uses 1749600 AHr per day and each rod needs 231 AHr for proper thickness, then 7574 rods can be produced per day. This compares favorably to the output of the line at standard operational speed of 7 feet per minute, which predicts 7560 rods per day (7 ft/min * 60 min/hr * 24 hr/day * 6 strands / 8 ft/rod). This is a 99.8+% correlation, indicating the theory virtually matches the actual!

Yet another chart can be generated to show the true cost to produce a rod inclusive of virtually all consumables. This final chart factors not only the cost of the copper and brightener additive, but also the electricity cost to plate the copper as well as the operational cost for using the CE additive. This chart also shows, for analysis purposes, the deposition costs per rod if there was no associated cost for the brightening additive.

Brightener $/gal	**25**	**50**	**12.5**	**0**
Rod cost total - Std	$2.579	$2.597	$2.570	$2.560
Rod cost total - CE	$2.544	$2.562	$2.534	$2.525
% Cost of Additive	0.54	1.08	0.27	0.00
% MFG change	-1.36	-1.35	-1.36	-1.37

Conclusion

The cost of the additive has almost no bearing on the cost of the final product. Doubling the Brightener cost or taking the cost to zero impacts the manufacturing costs by less than 0.6% from the norm. However, incorporation of a CE additive reduces application cost by nearly 1.4% per rod. As previously stated, brightening additives should be chosen by their performance not their cost, as their contribution to the bottom line is negligible. The cost of the product is really tied up in the copper deposited and the amount of energy it takes to place it there.

The data also shows that the copper application cost to produce a rod without conductivity enhancement and no associated brightener cost is $2.560. Comparably, the cost to produce a rod with the CE additive and brightener at $25/gal is $2.544. Therefore, even with no associated brightener cost, it is still $0.016/rod less expensive to use a conductivity-enhanced system. Within the scope of the model, a vendor would need to give away his additive and *pay* a user of a conductivity enhanced system an extra $120.00 per day to be cost competitive!

Finally, voltage decreases for desired amperage translating to lower kilowatt consumption is not unprecedented. The United States EPA provides the following paradigm in their effort to entice people away from hexavalent to trivalent chrome plating. [9]

Table 1. Comparison of Plating Bath Operating Characteristics

	Hexavalent	**Trivalent**
Temperature	110o F	120o F
Parts area per rack	12 ft2	13.8 ft2
Plating time per part	20 sec	100 sec
Current Density	200 amp/ft2	68 amp/ft2
Amperage for entire tank	2400 amp	2100 amp
Tank voltage	12 volt	8 volt
KWH/shift @ 85% rectifier efficiency	196 KWH	114 KWH

Note the amperage and tank voltage directly calculate the kWh per shift, less the rectifier efficiency (2400A x 12V x 8 Hr x .85 efficiency = 196 kWh). The lower voltage, trivalent chrome solution yields 88% of the AHr per shift from only 58% of the power. Kilowatt-hour savings from voltage reduction! This same phenomenon can now be exploited to help the metal finisher save 25-30% of the electrical costs associated with their copper plating.

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