The Effect of Barrel Design on Drag-out

By Frank Altmayer, MSF; Jeff Zak, P.E.; Kevin Wasag, CEF & Brian Cavanaugh, CEF

A search of the literature[1,2,4] found that there have been no independent studies comparing drag-out rates to barrel designs over the past 10 years. Meanwhile, newer barrel designs have been developed, and manufacturers of some of these newer designs have claimed significant improvements in drag-out losses.[3,5,6] Further, in the past three years, hundreds of metal finishing jobshops have entered into a voluntary agreement under the Strategic Goals Initiative (SGI), initiated by USEPA and co-sponsored by state environmental agencies, to reduce metals loading in wastes, reduce water consumption, and increase metals utilization dramatically. The Illinois Waste Management Resources Center agreed to fund a study that would produce a benchmark test to compare drag-out rates of plating barrels. This test was used to compare a small sample of barrel designs, to illustrate the efficacy of the test and provide the metal finishing industry with guidance for reducing drag-out rates, making it easier to achieve its goals under SGI. The information can also be used by equipment manufacturers to improve the designs of their plating barrels, so that lower levels of drag-out rates can result in lower levels of pollution on a nationwide basis.

The study was limited to two size ranges of plating barrels—small and large. For small barrels, (6 in. x 12 in.), testing showed that a reduction in drag-out rate as high as 48 percent may be achieved. For large barrels (16 in. x 34 in.), testing showed that a reduction as high as 44 percent may be obtained.

Fig. 1—Small barrel design #1.

This is an edited version of a paper presented at the 2002 AESF/EPA Conference for Environmental Excellence, Jan. 28-30, Orlando, FL.

Barrel Plating Idiosyncrasies

Barrel electroplating presents a higher degree of trouble in recycle-recovery schemes and in wastewater treatment operations because of the high drag-out rates that are caused by a combination of high surface area loads and retained liquid on the barrel and superstructure. While little can be done about the part loading/surface area in any given barrel plating operation, there have been revised barrel designs that may result in lower drag-out rates.

Complicating the issue of barrel design vs. drag-out reduction is the possibility that a given design may reduce drag-out rate, but will not provide long-term service. For example, some of these designs utilize thin-wall construction that may fracture over the life of the barrel, reducing productivity and decreasing the acceptability of alternate barrel designs by the industry.

This study intended to determine if significant reductions in drag-out can be achieved by replacing an existing barrel with a newer design.

Parameters of the Study

The study was funded and conducted under the WMRC ADOP²T program that assists industry members in achieving goals in pollution prevention. The study was further sponsored by an individual metal finishing jobshop, Northwestern Plating Works, located at 3136 S. Kolin Ave. Chicago IL. David Jacobs, president, allowed us to utilize an actual barrel plating line to conduct our experiments, and provided us with an example of a “traditional” plating barrel that we could use in our study.

Letters of invitation were sent to all barrel manufacturers listed in the *Metal Finishing Guidebook and Directory*. Of eight requests, three barrel manufacturers volunteered to supply us with barrels to include in the study. Also, three additional companies provided barrels for testing: Artistic Plating Company, Milwaukee, WI, John Lindstedt, president; Reinewald Plating Company, Chicago, IL, Ted Reinewald, president; and The Stutz Company, Gerry Stutz. The intent of our study was not to create a “competition” between barrel manufacturers to see who could lay claim to the lowest drag-out rate. Therefore, we do not identify which company manufactured which barrel.

This study had the following goals:

- To relate performance in drag-out reduction (or lack thereof) to specific design parameters, so that future barrel designs might incorporate the better ideas.
- To provide guidance to metal finishers regarding barrel designs that would allow them to reduce drag-out rates.
- To begin the establishment of a “benchmarking” system that could be used to determine if a metal finisher was using barrel plating equipment that was above average in reducing pollution loading.

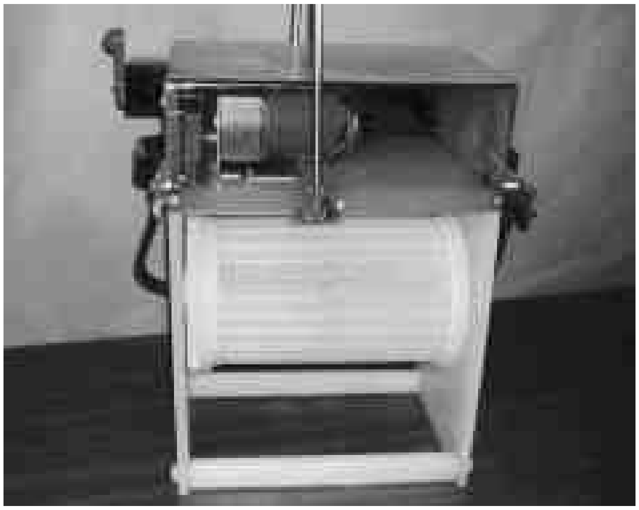

Fig. 2—Small barrel design #2.

Barrel Descriptions

Eight different plating barrels were evaluated in this study. To keep the comparisons as fair as possible, the barrels were separated into two size groups: four were small barrels (six-in. dia.) and four were large (14 to 16-in. dia.).

Evaluation of Small Barrels

Barrel Design #1

A 6-in. x 12-in. hexagonal plating barrel with replaceable mesh sides. Mesh sides have slots measuring 0.010-in. x 0.150-in., with approximately 384 slots per panel and six panels per side . Slots are tapered slightly and are larger on the outside of the barrel than on the inside. (See Fig. 1.)

Unique Feature(s)
Vertical drive shaft; replaceable mesh side panels; variable-speed drive system.

Approximate Cost
$1,000; $550 (cylinder, gears only)

Barrel Design #2

A 6-in. x 12-in. round , corrugated plating barrel with round holes. Holes are 3/32-in. in diameter and there are approximately 36 holes per square inch. The corrugated barrel provides more holes for drainage than a standard round barrel with the same dimensions. (See Fig. 2.)

Unique Feature(s)
Corrugated sidewalls; gear driven on only one side.
Approximate Cost
$1300; $510 (cylinder, gears only)

Barrel Design #3

A 6-in. x 12-in. octagonal plating barrel. The sides of the barrel are ribbed on the outside and have holes between the ribs. This barrel has square holes 0.100-in. x 0.100-in., with approximately 30 holes per square inch. (See Fig. 3.)

Unique Feature(s)
Ribbed walls increase strength while allowing areas with holes to be made thin. Gear-driven on both sides for better distribution of torque. The teeth on the gears are a large source of drag-out, however. Square holes help break surface tension of solutions to allow better drainage.
Approximate Cost
$1200; $600 (cylinder, gears only)

Barrel Design- #4

A 6-in. x 12-in. round plating barrel with finely woven mesh sides. The sides of the barrel are ribbed and covered in a woven plastic mesh. This barrel is gear-driven on one end, but the drive mechanism can be placed on either end of the barrel. (See Fig. 4.)

Unique Feature(s)
Woven mesh sides will retain all sizes of parts. The ribbed sides provide added strength. Gear-driven on only one side.
Approximate Cost
$1200; $650 (cylinder, gears only)

Evaluation of Large Barrels

Barrel Design #5

A 16-in. x 36-in. hexagonal plating barrel. This barrel has _-in. round holes and has approximately 695 holes per side. The barrel is mounted on a frame and is belt-driven. (See Fig. 5.)

Fig. 3—Small barrel design #3.

Fig. 4—Small barrel design #4.

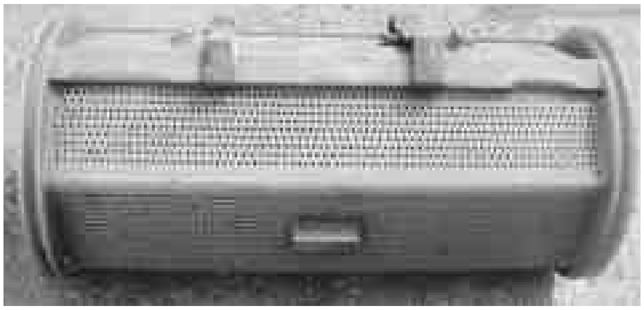

Fig. 5—Large barrel design #5.

Unique Feature(s)
Barrel is belt-driven, providing less surface area than a gear-driven barrel.
Approximate Cost
$2250; $1500 (cylinder, gears only)

Barrel Design #6

Barrel is a 14-in. x 36-in. hexagonal, belt-driven plating barrel. Unique hole design consisting of 3/32-in. round holes on the outside of the barrel with 0.220-in. square on the inside of the barrel walls tapered to the round external holes. There are approximately 16 holes per square inch. (See Fig. 6.)

Unique Feature(s)
Square-to-round hole design “funnels” the solution out of the barrel. Belt-driven design reduces overall surface area.
Approximate Cost
$2000; $1300 (cylinder, gears only)

Barrel Design #7

A portable oblique plater designed to replace 16-in. x 36-in. horizontal plating barrels.

Two rotating baskets with 3/16-in. diameter round holes. There are approximately 10 holes per square inch. The baskets are set at an angle of about 45^o. (See Fig. 7.)

Unique Feature(s)
Easier to load/unload manually or on an automated basis (no door); different baskets can be used in same frame, improving versatility.
Approximate Cost
$2,000

Barrel Design #8

A 14-in. x 36-in. hexagonal, gear-driven plating barrel. Staggered 0.16-in. x 1.0-in. and 0.16-in. x 0.5-in. slots. There are approximately 572 slots per side. (See Fig. 8.)

Fig. 6—Large barrel design #6.

Unique Feature(s)
Utilizes slots instead of holes. Irregular shape of slots prevents liquid from staying in opening.
Approximate Cost
$2400 (cylinder, gears only)

Testing/Evaluation Procedure

Drag-out Evaluation

The following equipment was used and conditions adhered to during the drag-out evaluation:

(a) Single process tank made of polypropylene
(b) Single static rinse tank
(c) Manual barrel handling
(d) Process solution contained only metal salt (copper sulfate), acid and water (no rinse aid)
(e) The increase in metal ion concentration in the rinse tank was measured after each barrel load rinse
(f) Barrels supplied from volunteer manufacturers or metal finishers

Process Solution

The drag-out evaluation was performed using a solution of copper sulfate, sulfuric acid and water. The process solution was kept as simple and free as possible of additional variables, such as wetters. (This also allows an individual metal finisher to duplicate the experiment with his own equipment in order to compare his performance with the equipment tested here.) The initial copper concentration in the copper sulfate solution ranged from 117.00 ppm to 846.00 ppm and is relatively unimportant to the results obtained, as long as the concentration of copper can be reliably measured in the rinse. Comparative tests conducted by others should use solutions of similar concentrations to minimize viscosity effects (from concentration differences).

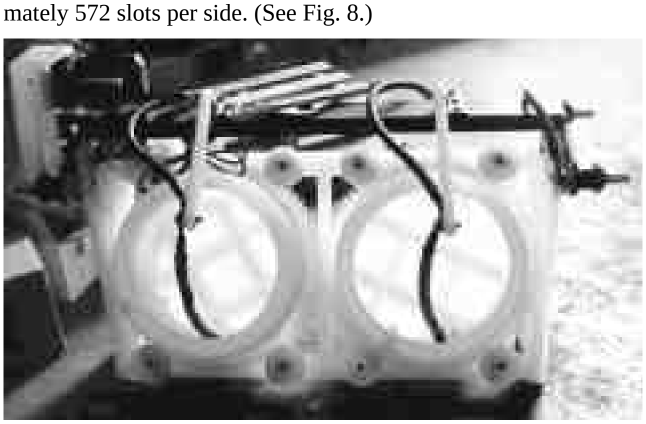

Fig. 7—Large barrel design #7.

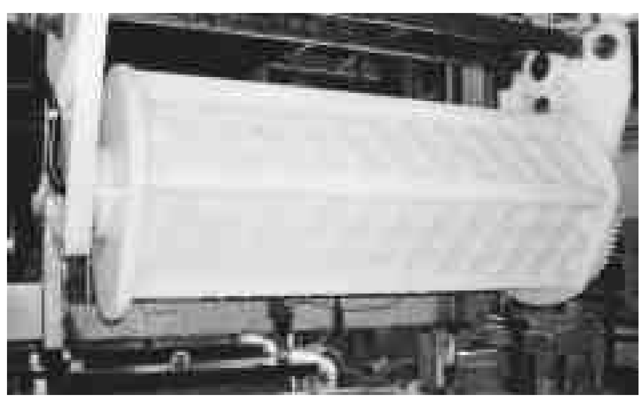

Fig. 8—Large barrel design #8.

Plating barrels tested were charged with six pounds of assorted stainless steel fasteners in the small barrels and 150 pounds of assorted stainless steel fasteners in the large barrels. The fasteners used were an equal mixture by weight of: 3/8-in. tapered hex washer head screws, 1-in. flat head Phillips screws, and 1-in. slotted head cap screws. The exact same load of fasteners was used for each barrel evaluation.

Three trials were performed on each plating barrel tested. The steps were:

(a) The copper sulfate solution was made up containing 117.00 to 846.00 ppm of copper.
(b) A second tank used to simulate a dead rinse was filled with tap water.
(c) A sample was collected from each tank prior to starting the test.
(d) The plating barrel to be tested was loaded with the proper amount of parts, then lowered into the copper sulfate solution.
(e) The barrel was rotated in the solution for 30 sec and then removed from the tank.
(f) After being removed from the copper sulfate solution tank, the barrel was rotated 1-1/2 revolutions, stopped, and allowed to drain for a total time of 30 sec above the process tank.
(g) The plating barrel was then lowered into the rinsewater and rotated for 30 sec.
(h) The plating barrel was then removed from the rinse tank, rotated 1-1/2 revolutions above the rinse tank, and allowed to drain for thirty sec.
(i) After water in the rinse tank was rinsed manually, a sample of the rinse tank was collected for use in determining the amount of drag-out.
(j) Steps (e) through (i) were then repeated nine more times to conclude the trial.
(k) After all 10 runs were completed, a final sample from the copper sulfate tank was taken to check if the amount of copper in the rinse tank matched the amount of copper removed from the copper sulfate tank.

After all 10 runs were completed, the 13 samples were analyzed for copper concentration using inductively coupled plasma (ICP). The concentrations provided by the analyses were used to calculate the amount of solution dragged out by each respective barrel tested.

Summary of Drag-out Rates—Small Barrels

Lowest drag-out rate: 142.2 mL, 23.7 mL/lb of parts
Highest drag-out rate: 270.8 mL, 45.1 mL/lb of parts
Average of four barrels: 200.35 mL, 33.4 mL/lb of parts

Testing showed that a significant reduction in drag-out rate can be achieved by replacing older design barrels with newer designs. A reduction as high as 48% may be obtained.

Summary of Drag-out Rates—Large Barrels

Lowest drag-out rate: 1670 mL, 11.18 mL/lb of parts*
Highest drag-out rate: 3881 mL, 25.9 mL/lb of parts*
Average of four barrels: 2079 mL, 13.9 mL/lb of parts

Testing showed that a significant reduction in drag-out rate can be achieved by replacing older design barrels with newer designs. A reduction as high as 44 percent may be obtained.*

* *This barrel was 14-in. x 36-in., while the others were 16-in. x 36-in. (We were unable to obtain a 16 x 36 slotted barrel, because the manufacturer declined participation in this study.) The difference has been adjusted in area of a solid 14 x 36 cylinder vs. a solid 16 x 36 cylinder (a factor of 1.3). The adjusted drag-out rate of this barrel is as shown. The actual results obtained with the smaller barrel are shown in the table on the following page.*

Economics of Small Barrels

A plater using a plating barrel of similar size to those evaluated should expect a drag-out rate of less than 200 mL (33.4 mL/lb of parts), when tested as described in this report for above-average levels of pollution prevention.

Barrel #1

Performed very well in the drag-out evaluation, dragging out an average of 147 mL per cycle. The low drag-out rate may be attributed to several design features:

- A vertical drive shaft that reduces the size of the gear (and, consequently, the number of teeth on the gear).
- A very narrow side frame (approximately 7.5 in. compared to 10 in. for the other small barrels evaluated).
- Unique gear positioning. It was observed that the more traditional gears tended to trap liquid between gear teeth.
- This barrel had a gear on only one side as compared to the others (gears on both sides).

All four of these designs reduced the amount of surface area of the barrel that comes in contact with the plating solution, thereby reducing the amount of "wetted" area of the barrel and the amount of solution dragged out by the barrel itself.

The low drag-out rate of Barrel #1 may also be attributed to the fact that the openings in the barrel are slots. As discovered while evaluating the large barrels, slots seem to be more efficient in draining solution than holes. Some barrel manufacturers claim that round holes tend to generate equal wall pressure and surface tension that causes the liquid to be entrapped within the holes.

Barrel #2

Produced 270.8 mL (45.1 mL/lb of parts) of drag-out rate, yielding results that were significantly above the average of the four barrels. The higher drag-out rate may be attributed to the fact that this barrel had two large gears that entrapped a significant amount of liquid. Also, the side frames were significantly wider than on Barrel #1 (10-in. x 10-in. vs. 7-in. x 10-in.). This barrel had an estimated 60 square inches more of surface area contacting the solution than Barrel #1.

Barrel #3

Produced 241.4 mL (40.2 mL/lb of parts) of drag-out rate, yielding results that were significantly above the average of the four barrels. The higher drag-out rate may be attributed to the fact that this barrel had two large gears that entrapped a significant amount of liquid. Also, the side frames were significantly wider than on Barrel #1 (10-in. x 10-in. vs. 7-in. x 10-in.). This barrel had an estimated 60 square inches more of surface area contacting the solution than Barrel #1.

Also, Barrel #2 was corrugated. Some think that the corrugated sides allow for an increased number of holes, thereby increasing drainage efficiency. The test data indicate otherwise.

Barrel #4

Yielded drag-out losses similar to Barrel #1, dragging out and average of 142 mL per use. Identical frame and gears as Barrels

#2 and #3. The barrel itself was constructed of a very fine, replaceable, woven mesh, however. Even with similar areas or wetted surface attributed to the large frame and the two large gears, this barrel outperformed drilled holes.

Equipment Economics—Small Barrels

The sponsor plating company for this project does not use barrels of this size. A metal finishing company that uses such small barrels can consider the following options:

Option 1—Replacing Barrels en Masse
A newer design barrel costs about $1,200 and saves about 140 mL of processing solution in each process step (soak clean, electroclean, acid dip, electroplate, post-plate dip) per run. Assuming 1,000 runs per barrel per year, and five processing steps, a total of 185 gal of processing solution would be saved annually. The value of the processing solution saved, plus labor to make up the solution, cost of chemicals for waste treatment, and cost of disposal of hazardous waste would need to be $3.24/gal for a two-year payback.

Option 2—Replacing Barrels As They Are "Consumed"
Because there is either no cost difference between the newer slotted barrels and traditional designs, or because mesh wall barrels may actually be lower in cost than traditional units, it appears that instant cost savings can be realized by replacing traditional barrel designs with one of the newer ones (mesh wall or slotted), when the need arises to replace a barrel. The mesh- walled barrels should be carefully evaluated for wall life. The mesh-walled barrel design tested was actually 20-30 percent lower in cost vs. traditional designs and allowed for easy replacement of the mesh.

Economics of Large Barrels

Barrel #5 (traditional design)

This barrel was in use by the sponsor plating company. The drag-out loss per barrel was almost 2300 mL (15.3 mL/lb of parts), which was below the average performance for the four barrels tested.

Barrel #6 (square-to-round holes)

This barrel was only 14-in. x 36-in., yet it yielded the highest level of drag-out in this evaluation, dragging out 2986 mL per cycle. If corrected for surface area (factor 1.3) to allow for a more accurate comparison with the 16 x 36 barrels, the drag-out rate would be 3881 mL (25.87 mL/lb of parts). In fairness, the holes in this barrel were too small for the parts that were plated. Larger holes would have been usable and would have resulted in better performance. If anything, the data reported confirm the importance of matching hole size to part size to reduce drag-out and improve plating efficiency (a task often ignored by metal finishers).

Drag-out Rates Measured from Various Barrel Types

Small Barrels

Barrel #	Trial Number	Pounds of Parts in Barrel	Drag-out* (mL)	Drag-out (mL) per Pounds of Parts*
1	1	6	160.3	26.7
	2	6	138.3	23.0
	3	6	142.5	23.7
			147.0	**24.5**
2	1	6	266.4	44.4
	2	6	256.7	42.8
	3	6	289.3	48.2
			270.8	**45.1**
3	1	6	245.7	40.9
	2	6	237.6	39.6
	3	6	240.8	40.1
			241.4	**40.2**
4	1	6	150.1	25.0
	2	6	138.4	23.1
	3	6	138.1	23.0
			142.2	**23.7**
Large Barrels				
5	1	150	2295	15.3
	2	150	2498	16.7
	3	150	2100	14.0
			2298	**15.3**
6	1	150	2916	19.4
	2	150	2933	19.6
	3	150	3109	20.7
			2986[2]/3881	**19.9/25.9**
7	1	150	1890[1]	12.6
	2	150	1633[1]	10.9
	3	150	1728[1]	11.5
			1750[1]	**11.7**
8	1	150	1394	9.3
	2	150	1337	8.9
	3	150	1125	7.5
			1285[2]/1670	**8.6[2]/11.2**

*Each individual trial result is an average of the 10 individual runs conducted in each trial.

1 The drag-out results for Barrel 7 were based on the first seven runs only. Runs 8, 9, and 10 in ***all three trials*** were erratic and significantly higher than the first seven runs. Including Runs 8, 9, and 10, the average drag-out for Barrel 7 would be 4800 mL.

2 The drag-out results for Barrels 6 and 8 are based upon testing a 14 x 36 barrel, while the others are 16 x 36. Second set of numbers is adjusted by a factor of 1.3 to compensate for size difference.

Barrel #7 (portable oblique barrel)

Test results for this barrel were based on only the first seven runs of the trial. Runs 8, 9, and 10 in all three trials showed **significantly** more drag-out than the runs 1-7, and the results, for unexplained reasons, were highly erratic. Therefore, only the data were used from the first seven runs in each trial, but all data are included in the appendix. Further investigation into the erratic results towards the end of each run is warranted, especially in light of the modified results being the second-best over-all performance in drag-out reduction. When the last three runs in each trail are deleted, this equipment yields similar results to the slotted barrel (after the slotted barrel results are adjusted for size differences).

The portable oblique plater yields lower levels of drag-out because each basket has a curved wall that acts much like a "funnel," channeling trapped solution to a "low-point" in the curved basket wall where hydraulic pressure tends to build up, forcing more liquid through the holes than if the walls were horizontal as in a conventional barrel.

Barrel #8 (slotted holes)

This was the best-performing large barrel in the study, dragging out 1285 mL, 8.6 mL/lb of parts (1670 mL, 11.2 mL/lb of parts when adjusted for size difference).

Although the dwell time of each barrel evaluated was 30 sec, test personnel noticed a significant difference in drain time. Water tended to "gush" out of this barrel in noticeably less time.

Equipment Economics—Large Barrels

The sponsor plating company for this project turns over approximately nine barrels per hour, or approximately 18,720 barrels per year in a nine-station plating tank. Because the slotted barrel drags out approximately 0.6 liters per cycle less than their current barrels (slotted barrel results adjusted to simulate a 16-in. diameter barrel), the pilot plating company would save approximately 3,100 gal each of soak cleaner, electrocleaner, acid and electroplating solution yearly. The metal finisher would have at least two options:

Option 1—Replacing All Barrels At One Time

Nine replacement slotted barrels would cost an estimated $21,600. Nine replacement portable oblique plating systems would cost about $18,000. For a two-year payback, the total sum value of the processing solutions plus labor costs to produce the solutions, plus waste treatment and disposal of hazardous waste would need to be $3.32/3.48/gal (portable oblique system/slotted barrel), which is below the cost/value of most barrel plating solutions used in metal finishing. Based on the drag-out evaluation results, the pilot plating company would save approximately 2,700 gal/yr of process solutions using the portable oblique system vs. the current plating barrel.

Option 2—Replacing Barrels As They Are "Consumed"

In this option, the metal finisher would replace barrels that are damaged beyond repair with one of the new designs. The "cost" basis would then be the difference between the cost of the new design vs. a traditional barrel.

For the slotted barrel, the difference in cost is approximately $900. If one of the nine barrels is replaced with the new design, it would save 344 gallons of processing solution per year. The total value of the saved processing solutions would need to be $1.31/gal for a two-year payback on the difference in cost between the two barrel designs.

For the portable oblique barrel, the difference in cost is $500 (cost of replacement of cylinder and gear for traditional barrel vs. cost of entire portable oblique barrel system). The total value of the processing solutions would then need to be $0.83 or less for a two-year payback.

A metal finisher replacing only a portion of a set of barrels may be faced with varying plating efficiencies between the newer designs (which tend to be higher in plating efficiency) and older designs. On manual lines, adjustments may be possible (the plater can remove the more inefficient barrel sooner), but on automated lines, it would probably be best to replace all barrels at one time.

The additional benefit of higher productivity with the new barrel designs was not part of this study and has therefore not been included in the economic analysis.

Recommendations

Based on this study, we would recommend that any metal finisher utilizing traditional barrels evaluate the economics of changing over to one of the newer designs, such as the portable oblique plating system or a newer-design horizontal barrel, incorporating either a mesh pattern or slots.

The portable oblique barrel is a radical departure from existing barrel plating technology and may offer advantages in plating efficiency not realized in traditional horizontal barrel systems. Careful evaluation for suitability is warranted, because of the radical design difference. The favorable cost comparison and significant reduction in drag-out rate make this system desirable.

The slotted barrel appears to be highly desirable in manual operations, where workers may not allow the barrel to drain fully. Because the slotted barrel appears to "gush" most of the liquid, it will drain in the first few seconds, it would appear that this equipment would allow most of the drag-out benefits, even when a worker impatiently moves a barrel to the next station prematurely.

This study was limited in scope. There are numerous other barrel designs that may offer even better results. The benchmarking procedure described in this report can be used by any finisher to yield comparative data on any of these barrels.

References

1. Casey, G.J. & Asher, R.K., "The Optimization of Barrel Zinc Plating Solutions," AESF Research Project 44, *Plating & Surface Finishing*, August, 1979, p. 51.
2. Craig Jr., S.E. & Harr, R.E., "A Theory of Metal Distribution During Barrel Plating," AESF Research Project 34, *Plating*, June, 1973, p. 617; December, 1973, p. 1101.
3. LaVine, Mark, "Choices," *Metal Finishing*, August 1998, p. 36.
4. Stein, Berl, Teichmann, Robert J. & Thompson, Peter L., "Mass Nickel Electroplating: A Comparison Study," *Metal Finishing*, July, 1992, p. 42.
5. Tremmel, Peter H., "Alternative Methods of Barrel Plating," *Metal Finishing*, March 1999, p. 34.
6. "Product Showcase: Barrel Plating," *Metal Finishing*, February, 1999, p. 48.

About the Authors

Frank Altmayer, MSF, AESF Fellow, is president of Scientific Control Labs, Inc., 3158 S. Kolin Ave., Chicago, IL 60623, and also serves as AESF technical director. He holds a BS in chemical engineering and a MS in metallurgy.

Jeff Zak, P.E., is the manager of engineering services at Scientific Control Labs, Inc. He holds a BS in chemical engineering.

Kevin Wasag, CEF, is the head metallurgist at Scientific Control Labs, Inc. He has a BS in metallurgy.

Brian Cavanaugh, CEF, is a staff scientist at Scientific Control Labs, Inc., He has a BS in environmental science.