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Waste Management and Research Center

Effect of Barrel Design On Dragout Rate

CMFI

The Chicago Metal Finishers Institute

RR-95
July 2002
Electronic Version

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Identification of barrels evaluated in this study:

#1 Tscherwitschke Galvanet - Series 03/18
#2 Stutz Company - Model 2000
#3 Sterling - Model B612K
#4 Hardwood Line Mesh Barrel - Model # not available
#5 Northwestern - No barrel identification
#6 Tscherwitschke - Galva E
#7 B & P Plating Supply Basket Plater - Model 2X18
#8 Hardwood Line Slotted Barrel

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ABSTRACT

New barrels for electroplating have been developed and manufacturers of some of these newer designs have claimed significant improvements in drag-out losses by their new barrels. Since water consumption and waste generation are directly tied to dragout rate from processing solutions, it is clear that there is a need to produce a method of evaluating such barrels, so that the user minimizes pollution.

This study, funded by The Illinois Waste Management Research Center (WMRC) produced a benchmark test to compare drag-out rates of plating barrels. The study used this test to compare two size ranges of plating barrels, small and large. For small barrels (6” x 12”), testing showed that a reduction in dragout rate, as high as 48%, may be achieved. For large barrels (16” x 36”), testing showed that a reduction as high as 44% may be obtained.

A survey was conducted to determine the relative durability of the barrels under study. The survey indicated that some of the barrels that produce lower levels of dragout (those using fine mesh) may unfortunately provide less service life, but other low dragout rate barrels offered service life that is similar to traditional barrels.

EXECUTIVE SUMMARY

Metal finishing operations typically process large numbers of small parts such as rivets and fasteners in perforated cylindrical barrels for operations such as electroplating, electropolishing, phosphating, black oxiding, and several other coating operations. Because this type of processing produces large volumes of entrapped liquid (called dragout), it is a major source of waste, as the dragout typically is waste treated yielding F-006 hazardous waste in many cases. Further, the dragout chemical must be rinsed during the processing steps and the volume rate of rinsewater is directly related to dragout rate. As an example, for an ideal single rinse, the rinsewater flow necessary to achieve a specific purity of rinse is determined by the equation: $F = D (C_t/C_r)$, where F is the rinse flow rate, D is the dragout rate and Ct/Cr is the rinse ratio (concentration of contaminant in the process tank divided by the concentration of the same contaminant in the rinse tank).

Therefore, reduction of dragout from barrel processing operations prevent pollution in several ways:

1. Reduces water consumption
2. Reduces hazardous waste generation
3. Reduces operating costs by saving chemicals purchased

The Illinois Waste Management Research Center agreed to fund a study that would produce a benchmark test to compare drag-out rates of plating barrels. We used this test to compare a small sample of barrel designs, in order to illustrate the efficacy of the test and provide the metal finishing industry with guidance that can be used to reduce dragout rates, making it easier to achieve their 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 dragout rates can result in lower levels of pollution on a nation-wide basis.

The study was limited to two size ranges of plating barrels, small and large.

For small barrels (6” x 12”), testing showed that a reduction in dragout rate, as high as 48%, can be achieved by replacing commonly used existing barrels constructed of solid walls and drilled holes with newer designs that incorporate meshed material into the walls of the barrel. The results obtained were:

Summary of Dragout Rates-Small Barrels

Lowest Dragout Rate	142.2 mL, 23.7 mL/lb. of parts
Highest Dragout Rate	270.8 mL, 45.1 mL/lb. of parts
Average of 4 Barrels	200.35 mL, 33.4 mL/lb. of parts

For large barrels (16" x 36"), testing showed that a reduction as high as 44% can be obtained. The barrels yielding the best results included one design that utilizes portable oblique rotating baskets as opposed to the commonly used plastic walls perforated with drilled holes. The other well performing design utilized slots instead of drilled holes, and this design yielded the best over-all results for large barrels. Test data generated showed:

Summary of Dragout Rates-Large Barrels	
Lowest Dragout Rate	1670 mL, 11.2 mL/lb. of parts
Highest Dragout rate	3881 mL, 25.9 mL/lb. of parts
Average of 4 Barrels	2400 mL, 16.3 mL/lb. of parts

The average dragout rates can be used as a "benchmark" by metal finishers in evaluating their own equipment. Barrels that dragout less than the average can be considered to be pollution prevention "friendly".

A survey was conducted to determine the relative durability of the barrels under study. The survey indicated that some of the barrels that produce lower levels of dragout may unfortunately provide less service life. These types of barrels typically utilize a fine mesh for part of the barrel wall.

Responses from metal finishers using barrels with fine meshed sides indicate that they last only about 33% as long on average as other barrels with polypropylene sides with holes/slots etc. Barrels with larger, reinforced mesh appeared to yield service life along the same level as traditional barrels.

Other failures commonly mentioned include gear failure. Alternate drive methods (belts for example) or better gear design appear to be desirable design features.

The newest barrel designs yielding the lowest dragout rates were too new to yield extensive service information. The slotted barrels and portable oblique basket plater were in use only for about 1 year without indication of any deterioration.

This study yielded the following:

1. We have developed a procedure for "benchmarking" barrels used in various metal finishing operations. This procedure is relatively easy to conduct and can be conducted by any metal finisher at reasonable effort and cost.

2. We have demonstrated that there is a significant difference in dragout rate produced by different barrel designs, with newer designs reducing dragout rate almost 50%. Our results compare favorably with those reported by one barrel manufacturer[4] who indicated that 26 to 49% reduction in dragout rate can be achieved by changing from a traditional barrel with drilled holes to one with a mesh pattern.

3. We have surveyed barrel users and found in general that barrels offer a long service life, with a possible exception to barrels that utilize a fine mesh as part of their wall design.

Using this study any metal finisher utilizing traditional barrels can evaluate the economics of changing over to one of the newer designs incorporating either a mesh pattern or slots and can significantly reduce pollution. Any metal finisher can also determine if his existing barrel equipment matches the performance of the newer designs.

Additional work that would be highly desirable is:

1. We would like to replace the conventional barrels at the metal finisher that allowed us to conduct this study with one of the newer designs and then obtain real-life dragout loss data, along with data on the ruggedness, plating efficiency differences (if any) and service life of the barrel.

2. We would like to have the opportunity to test barrels of other sizes and designs to yield a more complete guide for the metal finisher.

INTRODUCTORY MATERIAL

Barrel plating pre-dates the past century and is not significantly different today, in that a rotating cylinder with perforations for the purpose of allowing transfer of DC current and processing solution is still used today. However, there have been significant improvement claims in the technology of barrel plating, especially in the area of lowering dragout rates and improving barrel plating efficiencies.

The American Electroplaters and Surface Finishers Society (AESF, Orlando FL) conducted a research project (AESF Research Project 34) on the Theory of Metal Distribution in Barrel Plating[2], but this study did not cover barrel designs. AESF Research Project 44 studied the optimization of barrel zinc plating solutions[1]. Stein, Teichman and Thompson[4] compared vibratory plating equipment with barrel plating equipment for nickel plating of small parts, and concluded that barrel plating was "more suitable" than vibratory systems for nickel plating of small batches of small sized parts. More recently, LaVine[3] reported on a new barrel design incorporating a staggered cells and meshed walls to improve solution transfer and lower drag out rates. LaVine reported the new design could reduce dragout rates in nickel plating solutions by 26-49%, when compared to two "traditional" barrel designs. No details of the method of evaluations are given. Tremmel[5] mentions 'tapered slots" as part of a continuous plating system that is designed to replace conventional barrel plating equipment. Additional manufacturers lay claim to reduced dragout rates[6].

None of the above literature in our background search compared various barrel designs under identical conditions to yield comparative dragout rates and relate results to design parameters and barrel service life. The purpose of this study was to accomplish such a goal.

Barrel electroplating is commonly known to present a higher degree of trouble in recycle-recovery schemes and in wastewater treatment operations due to the high dragout rates during barrel processing. The high dragout rates 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 dragout rates.

Complicating the issue of barrel design vs. dragout reduction is the possibility that a given design may reduce dragout rate, but will not provide long term service, as 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:

a. If significant reductions in dragout can be achieved by replacing an existing barrel with a newer design.

b. If the newer design barrels offer similar barrel service life (when compared to conventional barrel designs).

The study was funded and conducted under the WMRC ADOP^{2}T program which assists industry members in achieving goals in pollution prevention. The study was further sponsored by an individual metal finishing job shop, Northwestern Plating Works, located at 3136 S. Kolin Ave. Chicago IL 60623. Mr. 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 Metal Finishing Guidebook and Directory. Of eight requests, three barrel manufacturers volunteered to supply us with barrels to include in the study (a fourth, Whyco Technologies also volunteered, but was not included due to miscommunication between the sponsor plating company and Whyco). Also, Artistic Plating Company, Milwaukee WI, Mr. John Lindstedt, President; Reinewald Plating Company, Chicago IL, Mr. Ted Reinewald, President ; and The Stutz Company, Mr. Gerry Stutz, added additional barrels for testing.

The intent of our study was not to create a "competition" between barrel manufacturers to see who could lay claim to the lowest dragout rate and therefore we do not identify which company manufactured which barrel.

This study had three goals:

1. Relate performance in dragout reduction (or lack thereof) to specific design parameters, so that future barrel designs might incorporate the better ideas.

2. Provide guidance to metal finishers as to barrel designs that would allow them to reduce dragout rates.

3. 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.

Equipment Descriptions

A total of eight (8) different plating barrels were evaluated in this study. To keep the comparisons as fair as possible, we separated the barrels into two size groups. Of the eight barrels evaluated, four were small barrels (six inch diameter) and four were large barrels (14 to 16 inch diameters). The following are descriptions of each barrel tested, any unique features in the barrel that may affect dragout, and the estimated cost of the barrel.

1. Small Barrels Evaluated

Barrel Design-1 (See Figure C-1)

Description of Barrel:
Barrel one is a 6” x 12” hexagonal plating barrel with replaceable mesh sides. Mesh sides have slots measuring 0.010” x 0.150” with approximately 384 slots per panel and 6 panels per side (See Figure C-2). Slots are tapered slightly and are larger on the outside of the barrel than on the inside.

Unique Feature(s):
Vertical Drive Shaft (See Figure C-3), Replaceable Mesh Side Panels, Variable Speed Drive System

Approximate Cost: $1,000 (as shown)
$ 550 (Cylinder, gears only)

Barrel Design-2 (See Figure C-4)

Description of Barrel
Barrel is a 6” x 12” round corrugated plating barrel with round holes. Holes are 3/32” 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.

Unique Feature(s)
Corrugated sidewalls (See Figure C-5), Gear driven on only one side.

Approximate Cost: $1300
$ 510 (Cylinder, gears only)

Barrel Design-3 (See Figure C-6)

Description of Barrel
Barrel is a 6” x 12” 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” x 0.100” with approximately 30 holes per square inch. (See Figure C-7)

Unique Feature(s)
Ribbed walls increase strength while allowing areas with holes to be made thin. The barrel is gear-driven on both sides for better distribution of torque. However, the teeth on the gears are a large source of dragout (See Figure C-8). Square holes help break surface tension of solutions to allow better drainage.

Approximate Cost: $1200
$ 600 (Cylinder, gears only)

Barrel Design-4 (See Figure C-9)

Description of Barrel
Barrel is a 6” x 12” round plating barrel with a finely woven mesh sides. The sides of the barrel are ribbed and covered in a woven plastic mesh (See Figure C-10). This barrel is gear driven on one end but the drive mechanism can be placed on either end of the barrel.

Unique Feature(s)
Woven mesh sides will retain all sizes of parts. The ribbed sides provide added strength. The barrel is gear-driven on only one side.

Approximate Cost $1200
$ 650 (Cylinder, gears only)

2. Large Barrels Evaluated

Barrel Design-5 (See Figure C-11)

Description of Barrel
Barrel is a 16” x 36” hexagonal plating barrel. This barrel has ¼” round holes and has approximately 695 holes per side. It is mounted on a frame and is belt driven.

Unique Feature(s)
The barrel is belt driven providing less surface area than a gear driven barrel (See Figure C-12).

Approximate Cost: $2250
$1500 (Cylinder, gears only)

Barrel Design-6 (See Figure C-13)

Description of Barrel
Barrel is a 14” x 36” hexagonal, belt driven plating barrel. This barrel has a unique hole design consisting of 3/32” round holes on the outside of the barrel with 0.220” square on the inside of the barrel walls tapered to the round external holes (See Figure C-14). There are approximately 16 holes per square inch.

Unique Feature(s)
A square-to-round hole design “funnels” the solution out of the barrel. The belt driven design reduces overall surface area.

Approximate Cost: $2000
$1300 (Cylinder, gears only)

Barrel Design-7 (See Figure C-15)

Description of Barrel
The barrel is a portable oblique plater designed to replace 16” x 36” horizontal plating barrels. This barrel has two (2) rotating baskets with 3/16” diameter round holes. There are approximately 10 holes per square inch. The baskets are set at an angle of about 45^{o}.

Unique Feature(s)
It is easier to load and unload manually or on an automated basis (no door) and different baskets can be used in same frame improving versatility.

Approximate Cost $2,000

Barrel Design-8 (See Figure C-16))

Description of Barrel
Barrel eight is a 14” x 36” hexagonal, gear driven plating barrel. This barrel has staggered 0.16” x 1.0” and 0.16” x 0.5” slots (See Figure C-17). There are approximately 572 slots per side.

Unique Feature(s)
It utilizes slots instead of holes. The irregular shape of slots prevents liquid from staying in opening.

Approximate Cost: $2400 (Cylinder, gears only)

METHODOLOGY

This section will discuss the methodologies used to determine dragout from the different barrels and barrel toughness.

Dragout evaluation

The following equipment was used and conditions adhered to during the dragout 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. Measured the increase in metal ion concentration in the rinse tank after each barrel load rinse
F. Barrels from volunteer manufacturers or metal finishers

Process Solution:
The dragout evaluation was performed using a solution of copper sulfate, sulfuric acid and water. These ingredients were chosen to keep the process solution as simple and free of additional

variables (such as wetters) as possible. This also allows an individual metal finisher to duplicate our 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).

Process Parts:

Plating barrels tested were charged with 6 pounds of assorted stainless steel fasteners for 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" tapered hex washer head screws, 1" flat head Phillips screws and 1" slotted head cap screws (See Figure C-18). The exact same load of fasteners was used for each barrel evaluation.

A total of three (3) trials were performed on each plating barrel tested. Each trial was conducted according to the following steps:

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 and then lowered into the copper sulfate solution.

e) The barrel was rotated in the solution for thirty seconds and then removed from the tank.

f) After being removed from the copper sulfate solution tank, the barrel was rotated 1-½ revolutions, stopped, and then allowed to drain for a total time of thirty seconds above the process tank.

g) The plating barrel was then lowered into the rinse water and rotated for thirty seconds.

h) The plating barrel was then removed from the rinse tank, rotated 1-½ revolutions above the rinse tank, and then allowed to drain for thirty seconds.

i) After mixing the water in the rinse tank manually, a sample of the rinse tank was collected for use in determining the amount of dragout.

j) Steps e through i were then repeated nine more times to conclude the trial.

k) After all ten (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 matches the amount of copper removed from the copper sulfate tank.

After all ten runs were completed, the samples (thirteen (13) total) were analyzed for copper concentration using ICP (Inductively Coupled Plasma). The concentrations provided by the analyses were used to calculate the amount of solution dragged out by each respective barrel tested. When calculating the dragout rate for each individual test run, the change in copper concentration in the primary tank after each individual trial run was deemed to be insignificant. The initial copper concentration in the primary tank was used in all trial run calculations.

2. Barrel Toughness

Since revised barrel design may be a weaker structure, we need to evaluate if the best performing dragout barrel design has any different toughness versus the standard barrel. Because of the relatively high costs of barrels, none of the barrel donators would agree to have us destroy or damage the barrels by conducting accelerated rotational load tests in order to determine the strength/toughness of the barrel. Instead, many of the barrel suppliers suggested an alternate method for obtaining information on barrel toughness. This involved conducting a survey of barrel platers that have been actually used the barrels for long periods of time.

Questionnaires asking for information on barrel type and barrel toughness were sent out to over 200 barrel electroplaters throughout the United States. As of July 15, 2001, approximately 40 completed questionnaires were received containing 58 comments on different barrel designs.

RESULTS

Table 1: Dragout Rates Measured from Various Barrel Types

Barrel Number	Trial Number	Pounds of Parts in Barrel	Dragout* (mL)	Dragout (mL) per Pounds of Parts*
Small Barrels				
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 ten individual runs conducted in each trial*

*1 The dragout 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 dragout for Barrel7 would be 4800 mLs.*
2 The dragout 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 are adjusted by a factor of 1.3 to compensate for size difference.

Barrel Toughness Results

The following is a summary of the completed questionnaires received from polling barrel electroplaters regarding barrel toughness:

Table 2: Summary of Questionnaire Responses Regarding Barrel Toughness

Barrel Type	Number of Responses	Range of Average Life of Barrel	Average Life of Barrel from Responses	Most Common Cause of Failures
Round Barrel with Round Holes	12	2-10 years	6.5 Years	Gears Fail and Holes Enlarge
Hexagonal Barrel with Fine Mesh	5	1-12 years	4.5 Years	Mesh Failure
Hexagonal Barrel with Large Mesh	2	10-12 Years	11 Years	Mesh Failure
Hexagonal Barrel with Square Holes Tapering to Round	2	12 Years	12 Years	Polypropylene Failure
Basket Plater with Round Holes	1	Unknown	Unknown	Barrel is only 1 year old
Hexagonal Barrel with Small Round Holes	19	5 – 25 Years	12 Years	Gears Fail, Panels Split
Hexagonal Barrel with Large Round Holes	13	5 – 25 Years	11 Years	Gears Fail, Panels Split
Hexagonal Barrel with Tapered Holes	1	5 Years	5 Years	Aging of Polypropylene
Hexagonal Barrel with Slots	1	Unknown	Unknown	Barrel is only 1 year old
Hexagonal Barrel with Round Countersunk Holes	2	3-15	NA	Holes Close Panels Split

RESULT SUMMARY

Summary of Dragout Rates-Small Barrels

Lowest Dragout Rate	142.2 mL, 23.7 mL/lb. of parts
Highest Dragout rate	270.8 mL, 45.1 mL/lb. of parts
Average of 4 Barrels	200.35 mL, 33.4 mL/lb. of parts

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

Summary of Dragout Rates-Large Barrels

Lowest Dragout Rate	1670 mL, 11.18 mL/lb of parts*
Highest Dragout Rate	3881 mL, 25.9 mL/lb. of parts*
Average of 4 Barrels	2079 mL, 13.9 mL/lb. of parts

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

** This barrel was 14" x 36 vs. while the others were 16" x 36" (we were unable to obtain a 16 x 36 slotted barrel, as the manufacturer declined participation in this study). We have adjusted by the difference in area of a **solid** 14 x 36 cylinder vs a **solid** 16 x 36 cylinder (a factor of 1.3) the adjusted dragout rate of this barrel is as shown. The actual results obtained with the smaller barrel are shown in Table 2.*

DISCUSSION

Small Barrel Dragout Results

A plater using a plating barrel of similar size to those we evaluated should expect a dragout 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:
This performed very well in the dragout evaluation, dragging out an average of 147 ml per cycle. The low dragout rate may be attributed to several design features:

1) A vertical drive shaft that reduces the size of the gear and consequently, the number of teeth on the gear (See Figure C-3).

2) A very narrow side frame (approximately 7.5 inches compared to 10 inches for the other small barrels we evaluated).

3) Unique gear positioning (See Figure C-3). We noticed that the more traditional gears tended to trap liquid between gear teeth.

4) This barrel had a gear on only one side as compared to the others (gears on both sides).

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

The low dragout rate of Barrel 1 may also be attributed to the fact that the openings in the barrel are slots (See Figure C-2). 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:
This barrel 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 dragout rate may be attributed to the fact that this barrel had two, large gears that entrapped a significant amount of liquid (See Figure C-8). Also, the side frames were significantly wider than on Barrel 1 (10" x 10" vs. 7" x 10"). This barrel had an estimated 60 square inches more of surface area contacting the solution than Barrel 1.

Barrel 3:
This barrel produced 241.4 mL (40.2 mL/lb. of parts) of dragout rate, yielding results that were significantly above the average of the four barrels. The higher dragout rate may be attributed to the fact that this barrel had two, large gears that entrapped a significant amount of liquid (See Figure C-8). Also, the side frames were significantly wider than on Barrel 1 (10" x 10" vs. 7" x 10"). This barrel had an estimated 60 square inches more of surface area contacting the solution than Barrel 1.

Also, Barrel 2 was corrugated (See Figure C-5). Some think that the corrugated sides allow for an increased number of holes, thus, increasing drainage efficiency. The test data indicate otherwise.

Barrel 4:
This barrel yielded dragout losses similar to Barrel 1, dragging out and average of 142 mL per use. This barrel had the identical frame and gears as Barrels 2 and 3. However, the barrel itself was constructed of a very fine, replaceable, woven mesh. Even with similar areas or wetted surface due to the large frame and the two large gears, this barrel outperformed drilled holes.

Economics-Small Barrels

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

Option 1 Replacing Barrels En Masse:
A newer design barrel costs about $1200.00 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 5 processing steps, a total of 185 gallons 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/gallon for a two-year payback.

Option 2 Replacing Barrels As They Are "Consumed":
Since 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), as the need to replace a barrel arises. The mesh walled barrels should be carefully evaluated for wall life. The mesh walled barrel design we tested was actually 20-30% lower in cost vs. traditional designs and allowed for easy replacement of the mesh.

Large Barrel Dragout Results

Barrel Number 5 (traditional design):
This barrel was in use by the sponsor plating company. The dragout 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 Number 6 (the square to round holes):
This barrel was only 14" x 36", yet it yielded the highest level of dragout 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 dragout 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 dragout and improve plating efficiency (a task often ignored by metal finishers).

Barrel 7 (the 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 dragout than the Runs 1-7 and the results, for unexplained reasons were highly erratic (see graphs in appendix). We have therefore used the data from only the first 7 runs in each trial, but include all our data 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 dragout 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 dragout 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 barrel):
This was the best performing large barrel in our 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 barrels evaluated was 30 seconds, test personnel noticed a significant difference in drain time. Water tended to "gush" out of this barrel in noticeably less time.

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 (9) station plating tank. Since the slotted barrel drags out approximately 0.6 liters per cycle less than their current barrels (slotted barrel results adjusted to simulate a 16" diameter barrel), the pilot plating company would save approximately 3100 gallons each of soak cleaner, electrocleaner, acid and electroplating solution each year. 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 $21,600.00. Nine replacement portable oblique plating systems would cost about $18,000.00. 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 per gallon for the portable oblique system and slotted barrel, respectively, which is below the cost/value of most barrel plating solutions used in metal finishing. Based on the dragout evaluation results, the pilot plating company would save approximately 2700 gallons of process solutions per year using the portable oblique system versus 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 $900.00. 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 per gallon 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 $500.00 (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 per gallon 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 (tend to be higher in plating efficiency) and older designs. On manual lines, adjustments may be possible (the plater can remove the more efficient barrel sooner), but on automated lines, it would most 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 our economic analysis.

Discussion of Survey Results

Responses from metal finishers using barrels with fine meshed sides indicate that they last only about 33% as long on average as other barrels with polypropylene sides with holes/slots etc. Barrels with larger/reinforced mesh appeared to yield service life along the same level as traditional barrels. Service on fine meshed barrels was reported at an average of 4.5 years by 5 users, with the shortest level of service at 1 year and the longest at 12. Large meshed and "conventional" barrels (horizontal cylinder with drilled holes) yielded a service life range of 5-25 years, with an average of about 12 years before evidencing wall failures.

Other failures commonly mentioned include gear failure. Alternate drive methods (belts for example) or better gear design appear to be desirable design features, especially since at least some gears were found to exacerbate dragout levels.

The newest barrel designs yielding the lowest dragout rates were too new to yield extensive service information. The slotted barrels and portable oblique basket plater were in use only for about 1 year without indication of any deterioration.

CONCLUSIONS

1. We have developed a procedure for "benchmarking" barrels used in various metal finishing operations. This procedure is relatively easy to conduct and can be conducted by any metal finisher at reasonable effort and cost.

2. We have demonstrated that there is a significant difference in dragout rate produced by different barrel designs, with newer designs reducing dragout rate almost 50%. Our results compare favorably with those reported by one barrel manufacturer[4] who indicated that 26 to 49% reduction in dragout rate can be achieved by changing from a traditional barrel with drilled holes to one with a mesh pattern.

3. We have surveyed barrel users and found in general that barrels offer a long service life, with a possible exception to barrels that utilize a fine mesh as part of their wall design.

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 realizable in traditional horizontal barrel systems. Careful evaluation for suitability is warranted, due to the radical design difference. The favorable cost comparison and significant reduction in dragout rate make this system desirable.

The slotted barrel appeared to us to be highly desirable in manual operations, where workers may not allow the barrel to drain fully. Since 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 dragout benefits, even when a worker impatiently moves a barrel to the next station prematurely.

We are aware that our study was limited in scope and that there are numerous other barrel designs that may offer even better results. The benchmarking procedure described in this report can be used to yield comparative data on any of these barrels.

Additional work that would be highly desirable is:

1. We would like to replace the conventional barrels at the metal finisher that allowed us to conduct this study with one of the newer designs and then obtain real-life dragout loss data, along with data on the ruggedness, plating efficiency differences (if any) and service life of the barrel.

2. We would like to have the opportunity to test barrels of other sizes and designs to yield a more complete guide for the metal finisher.

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2. Craig Jr., S. E. and Harr, R. E., "A Theory of Metal Distribution During Barrel Plating", AESF Research Project 34, Plating. vol. 60, June, 1973, page 617, December, 1973, page 1101.

3. LaVine, Mark, "Choices", Metal Finishing. vol. 96, August 1998, page 36-40.

4. Stein, Berl, Teichmann, Robert J. and Thompson, Peter L., "Mass Nickel Electroplating: A Comparison Study", Metal Finishing. vol. 90, July, 1992, page 42-45.

5. Tremmel, Peter H., "Alternative Methods of Barrel Plating", Metal Finishing. vol. 97, March 1999, page 34.

6. Product Showcase: Barrel Plating, Metal Finishing. vol. 97, February, 1999, page 48-53.

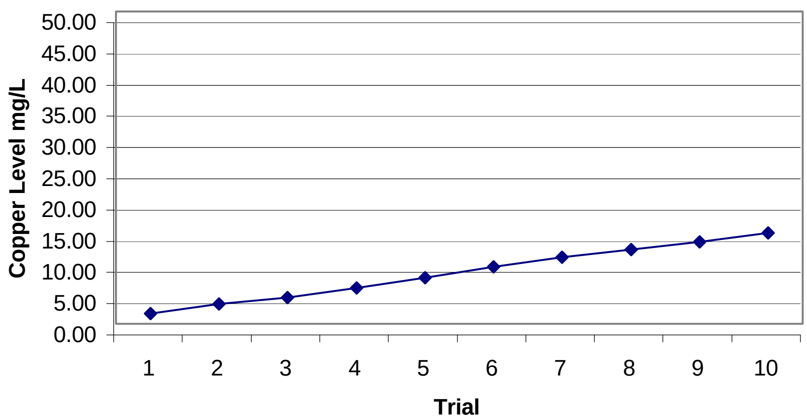
Appendices

Appendix A: Dragout Data/Graphs/Figures

Figure A-1 - Graphed Raw Dragout Data - Barrel Design 1 - Trial 1

Results **Trial #1** **Barrel Design #1**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	419.00	------------	
Final	417.00	------------	26.7144
Blank	0.00	------------	
#1	1.63	178.95	
#2	3.13	164.68	
#3	4.22	119.67	
#4	5.69	161.38	
#5	7.34	181.15	
#6	9.07	189.93	
#7	10.70	178.95	
#8	11.90	131.74	
#9	13.10	131.74	
#10	14.60	164.68	
		160.29	



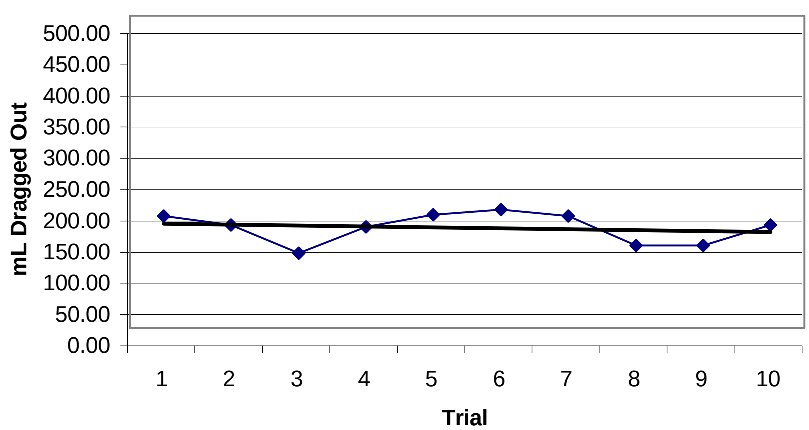
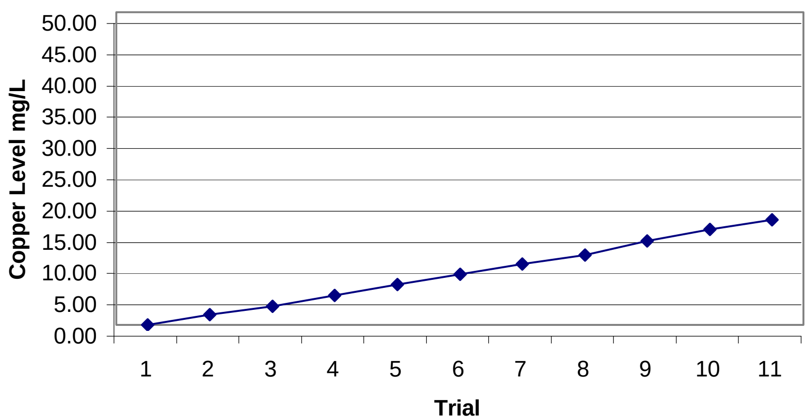


Figure A-2 - Graphed Raw Dragout Data - Barrel Design 1 - Trial 2

Results **Trial #2** **Barrel Design #1**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL		ml dragged out per lbs/parts
Initial	559.00	------------		
Final	530.00	------------		23.04114
Blank	0.00	------------		
#1	1.69		139.07	
#2	3.01		108.62	
#3	4.72		140.72	
#4	6.46		143.18	
#5	8.05		130.84	
#6	9.77		141.54	
#7	11.20		117.67	
#8	13.40		181.04	
#9	15.30		156.35	
#10	16.80		123.43	
			138.25	



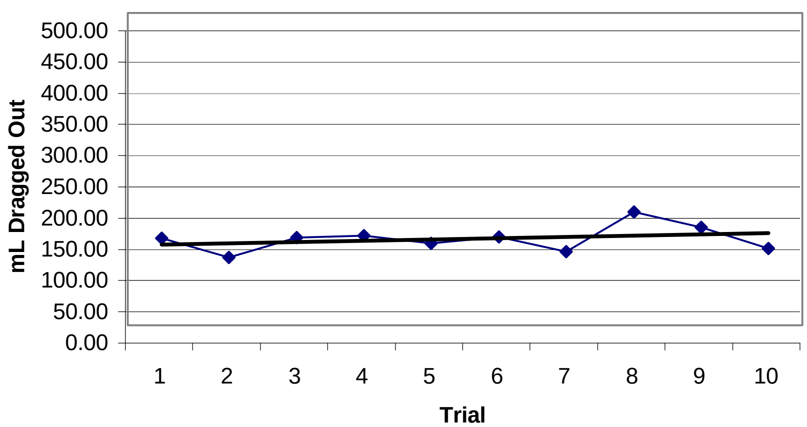
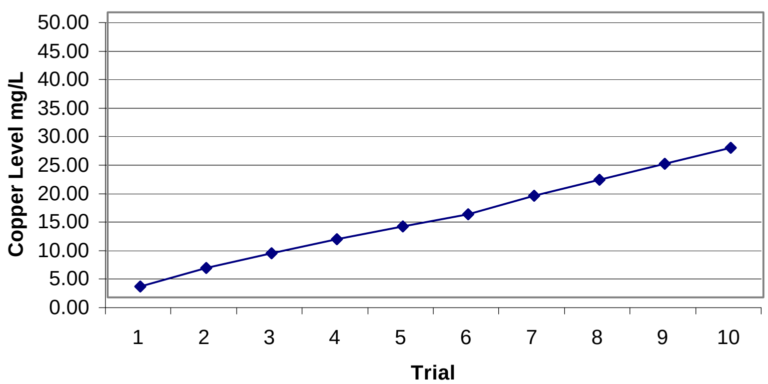


Figure A-3 - Graphed Raw Dragout Data - Barrel Design 1 - Trial 3

Results **Trial #3** **Barrel Design #1**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	846.00	------------	
Final	757.00	------------	23.7431
Blank	0.00	------------	
#1	1.96	106.57	
#2	5.21	176.71	
#3	7.70	135.39	
#4	10.20	135.93	
#5	12.40	119.62	
#6	14.60	119.62	
#7	17.80	174.00	
#8	20.60	152.25	
#9	23.40	152.25	
#10	26.20	152.25	
		142.46	



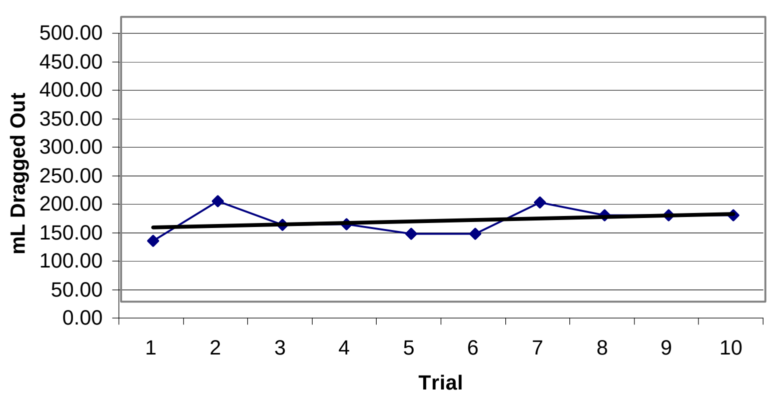
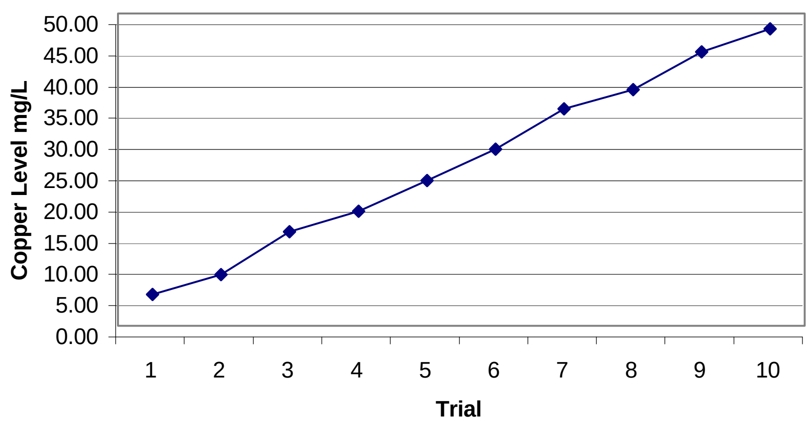


Figure A-4 - Graphed Raw Dragout Data - Barrel Design 2 - Trial 1

Results **Trial #1** **Barrel Design #2**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	820.00	------------	
Final	761.00	------------	44.39187
Blank	0.02	------------	
#1	4.99	278.80	
#2	8.23	181.76	
#3	15.10	385.39	
#4	18.30	179.51	
#5	23.30	280.49	
#6	28.30	280.49	
#7	34.70	359.02	
#8	37.80	173.90	
#9	43.90	342.20	
#10	47.50	201.95	
		266.35	



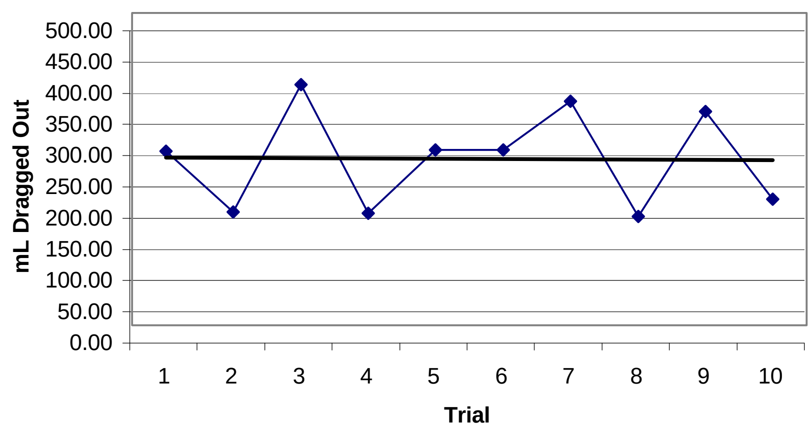
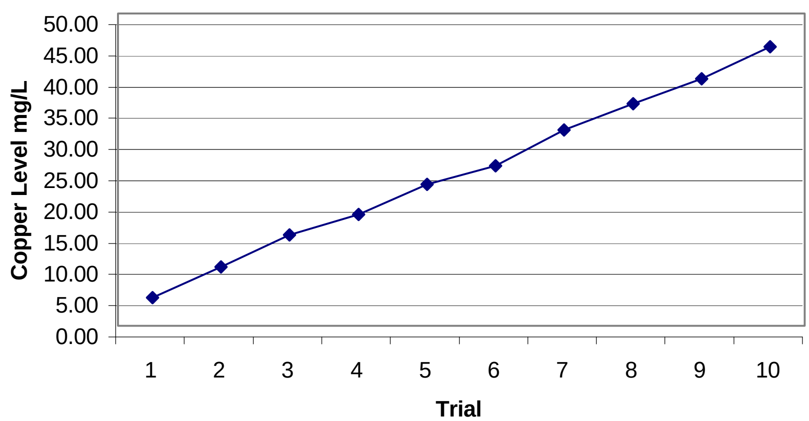


Figure A-5 - Graphed Raw Dragout Data - Barrel Design 2 - Trial 2

Results **Trial #2** **Barrel Design #2**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	801.00	------------	
Final	763.00	------------	42.78402
Blank	0.00	------------	
#1	4.53	260.15	
#2	9.42	280.82	
#3	14.60	297.48	
#4	17.80	183.77	
#5	22.60	275.66	
#6	25.60	172.28	
#7	31.40	333.08	
#8	35.60	241.20	
#9	39.60	229.71	
#10	44.70	292.88	
		256.70	



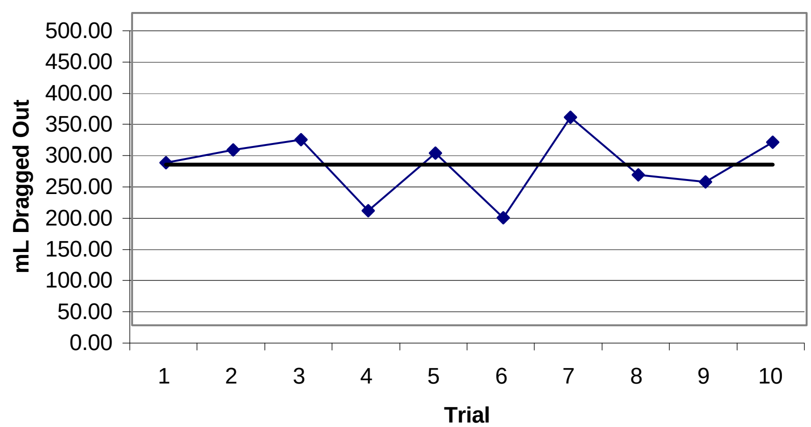
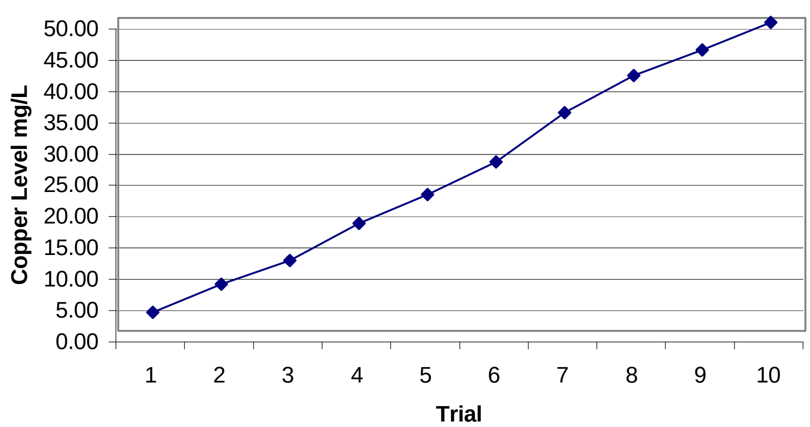


Figure A-6 - Graphed Raw Dragout Data - Barrel Design 2 - Trial 3

Results **Trial #3** **Barrel Design #2**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL		ml dragged out per lbs/parts
Initial	784.00	------------		
Final	739.00	------------		48.21003
Blank	0.00	------------		
#1	2.98		174.85	
#2	7.51		265.79	
#3	11.20		216.51	
#4	17.20		352.04	
#5	21.80		269.90	
#6	27.00		305.10	
#7	34.90		463.52	
#8	40.80		346.17	
#9	44.90		240.56	
#10	49.30		258.16	
			289.26	



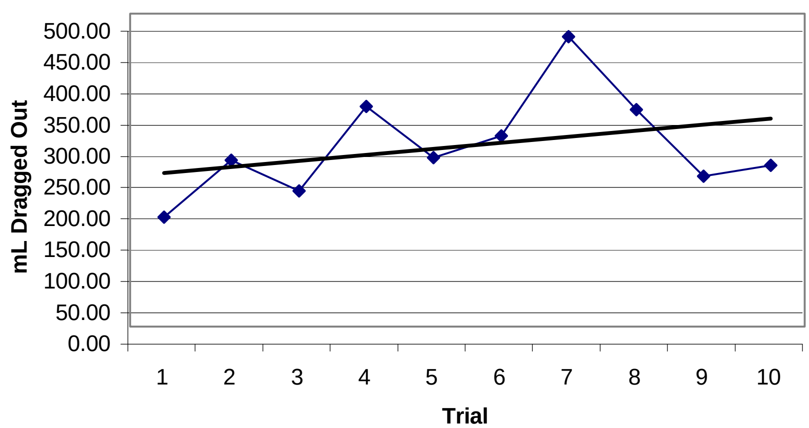
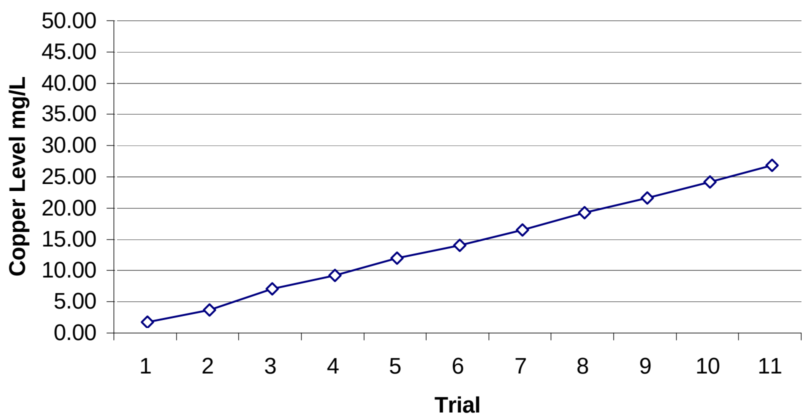


Figure A-7 - Graphed Raw Dragout Data - Barrel Design 3 - Trial 1

Results **Trial #1** **Barrel Design #3**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL		ml dragged out per lbs/parts
Initial	470.00	------------		
Final	397.00	------------		40.94326
Blank	0.00	------------		
#1	1.98		193.79	
#2	5.31		325.91	
#3	7.44		208.47	
#4	10.20		270.13	
#5	12.30		205.53	
#6	14.80		244.68	
#7	17.50		264.26	
#8	19.90		234.89	
#9	22.40		244.68	
#10	25.10		264.26	
			245.66	



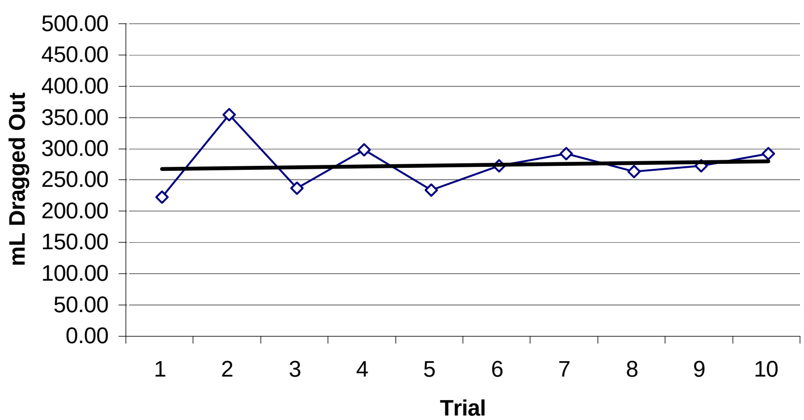
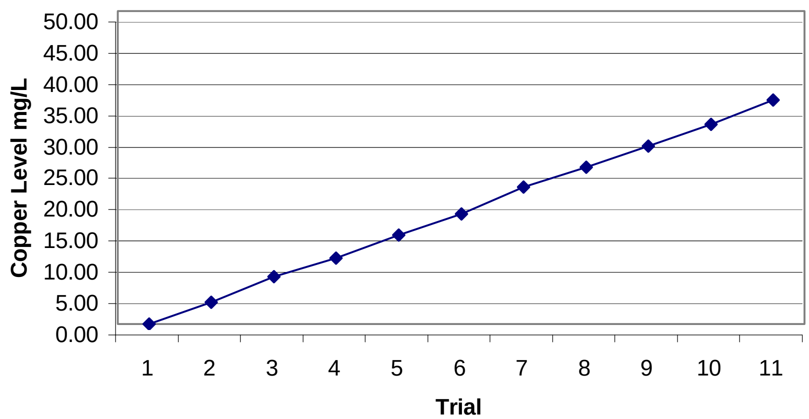


Figure A-8 - Graphed Raw Dragout Data - Barrel Design 3 - Trial 2

Results **Trial #2** **Barrel Design #3**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL		ml dragged out per lbs/parts
Initial	693.00	------------		
Final	677.00	------------		39.60558
Blank	0.00	------------		
#1	3.43		227.68	
#2	7.60		276.80	
#3	10.50		192.50	
#4	14.20		245.60	
#5	17.60		225.69	
#6	21.90		285.43	
#7	25.10		212.41	
#8	28.40		219.05	
#9	31.90		232.32	
#10	35.80		258.87	
			237.63	



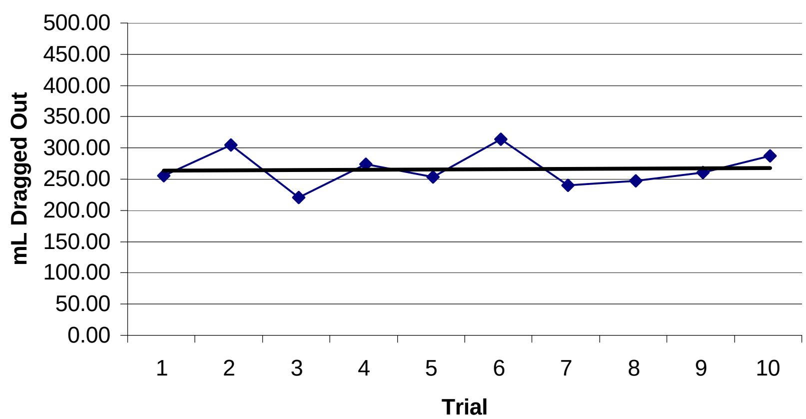
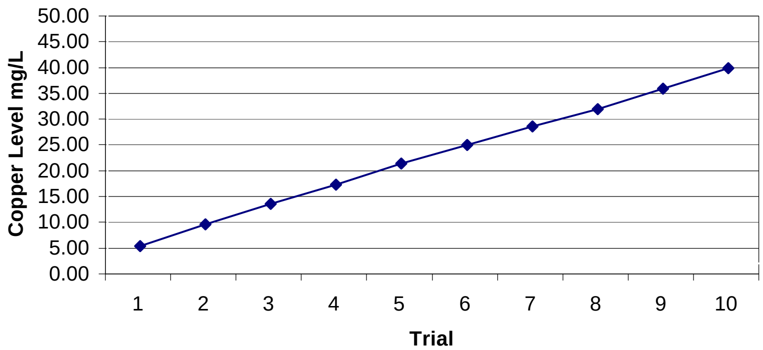


Figure A-9 - Graphed Raw Dragout Data - Barrel Design 3 - Trial 3

Results **Trial #3** **Barrel Design #3**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	722.00	------------	
Final	680.00	------------	40.1385
Blank	0.05	------------	
#1	3.37	214.71	
#2	7.52	264.40	
#3	11.50	253.57	
#4	15.20	235.73	
#5	19.40	267.59	
#6	23.00	229.36	
#7	26.50	222.99	
#8	29.90	216.62	
#9	33.90	254.85	
#10	37.80	248.48	
		240.83	



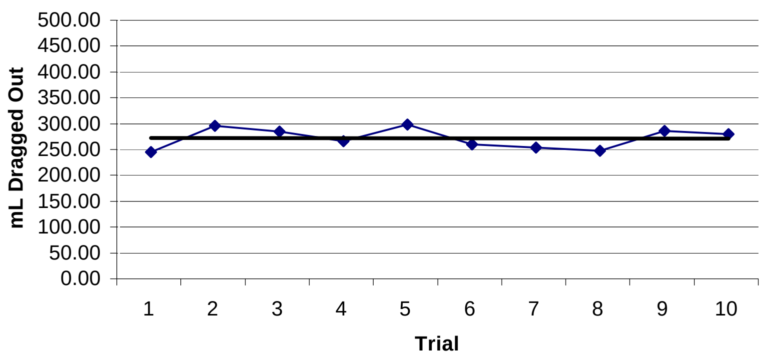
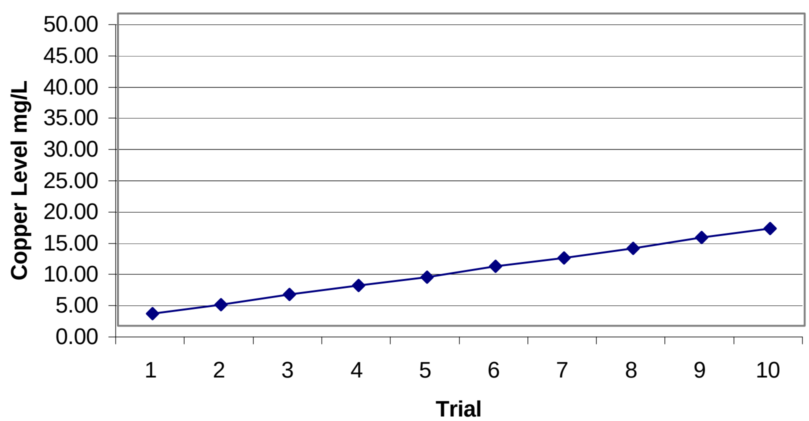


Figure A-10 - Graphed Raw Dragout Data - Barrel Design 4 - Trial 1

Results **Trial #1** **Barrel Design #4**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	478.00	------------	
Final	471.00	------------	25.02092
Blank	0.00	------------	
#1	1.93	185.73	
#2	3.40	141.46	
#3	4.99	153.01	
#4	6.42	137.62	
#5	7.80	132.80	
#6	9.50	163.60	
#7	10.90	134.73	
#8	12.40	144.35	
#9	14.10	163.60	
#10	15.60	144.35	
		150.13	



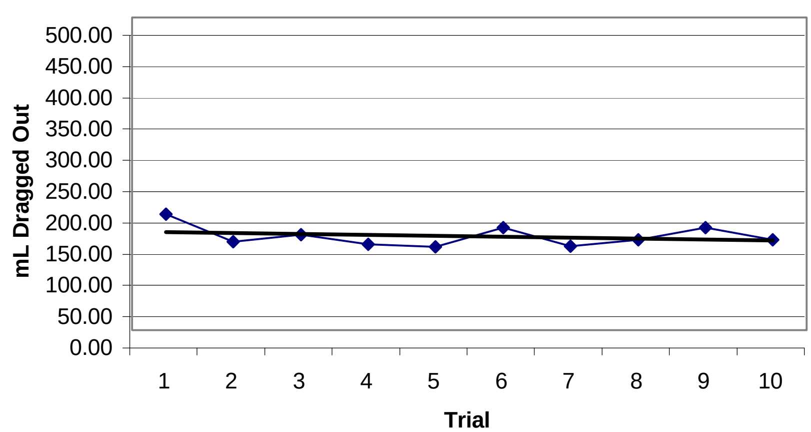
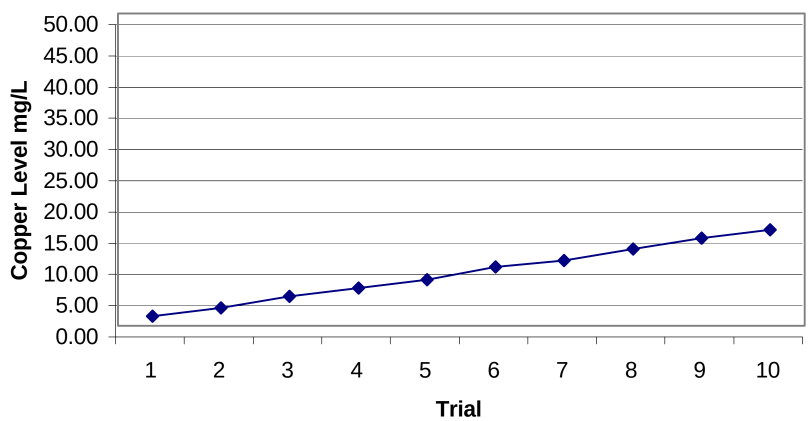


Figure A-11 - Graphed Raw Dragout Data - Barrel Design 4 - Trial 2

Results **Trial #2** **Barrel Design #4**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	512.00	------------	
Final	507.00	------------	23.0599
Blank	0.00	------------	
#1	1.56	140.16	
#2	2.87	117.70	
#3	4.67	161.72	
#4	6.09	127.58	
#5	7.33	111.41	
#6	9.47	192.27	
#7	10.40	83.55	
#8	12.30	170.70	
#9	14.00	152.73	
#10	15.40	125.78	
		138.36	



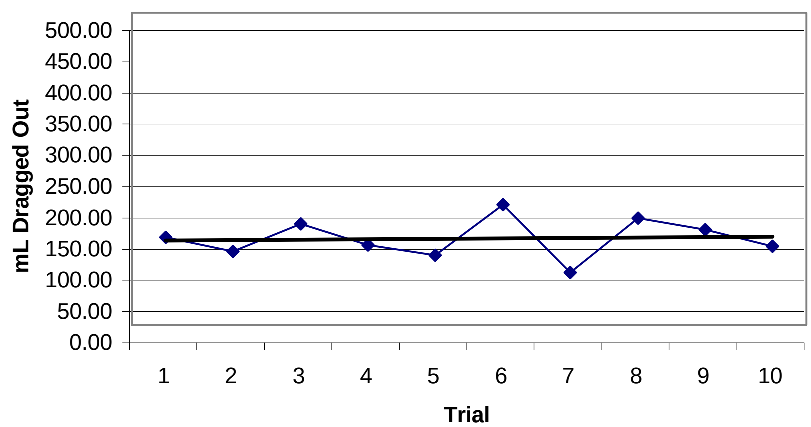
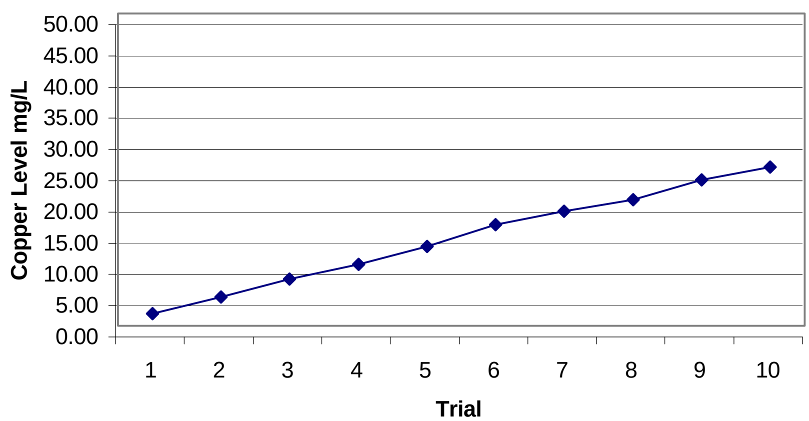


Figure A-12 - Graphed Raw Dragout Data - Barrel Design 4 - Trial 3

Results **Trial #3** **Barrel Design #4**

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL		ml dragged out per lbs/parts
Initial	846.00	------------		
Final	757.00	------------		23.01812
Blank	0.00	------------		
#1	1.94		105.48	
#2	4.64		146.81	
#3	7.49		154.96	
#4	9.87		129.41	
#5	12.70		153.88	
#6	16.20		190.31	
#7	18.30		114.18	
#8	20.20		103.31	
#9	23.40		174.00	
#10	25.40		108.75	
			138.11	



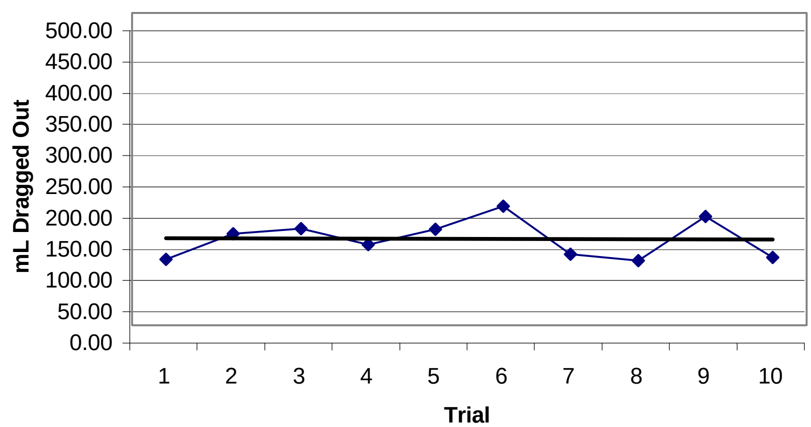


Figure A-13 - Graphed Raw Dragout Data - Barrel Design 5 - Trial 1

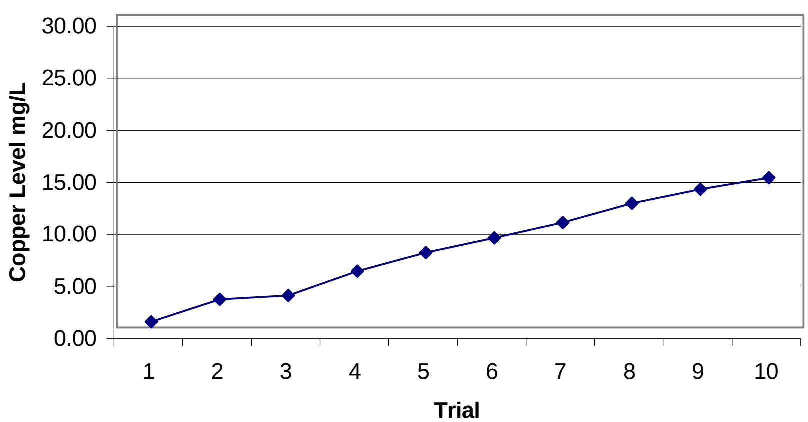
Results **Trial #1** **Barrel Design #5**

653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	394.00	------------
Final	382.00	------------
Blank	0.56	------------
#1	0.55	-16.58
#2	2.68	3531.80
#3	3.07	646.67
#4	5.39	3846.84
#5	7.20	3001.20
#6	8.61	2337.95
#7	10.10	2470.60
#8	11.90	2984.62
#9	13.30	2321.37
#10	14.40	1823.93
		2294.84

ml dragged out per lbs/parts

15.29894



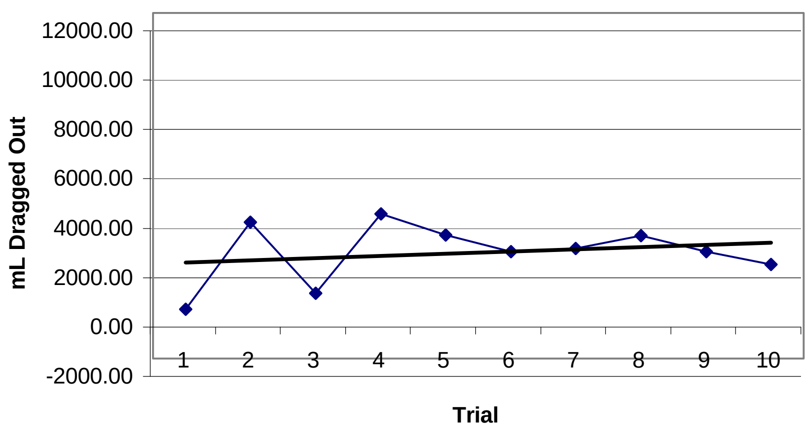


Figure A-14 - Graphed Raw Dragout Data - Barrel Design 5 - Trial 2

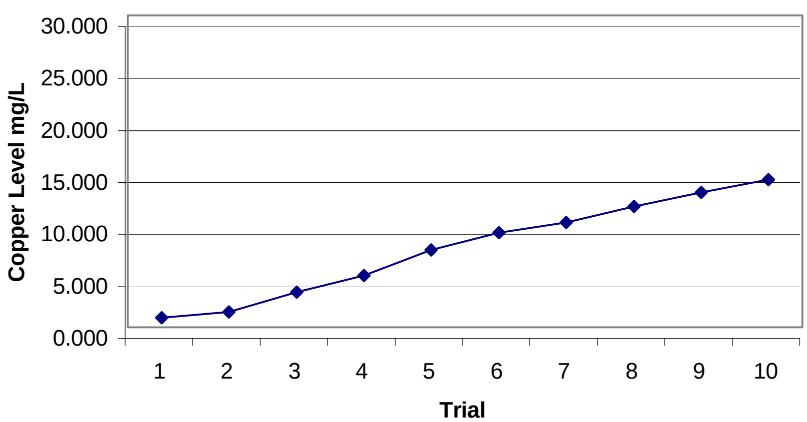
Results **Trial #2** **Barrel Design #5**

653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	362.00	------------
Final	353.00	------------
Blank	0.356	------------
#1	0.927	1030.48
#2	1.450	943.86
#3	3.370	3465.02
#4	5.000	2941.65
#5	7.450	4421.51
#6	9.120	3013.84
#7	10.100	1768.60
#8	11.600	2707.04
#9	13.000	2526.57
#10	14.200	2165.64
		2498.42

ml dragged out per lbs/parts

16.65614



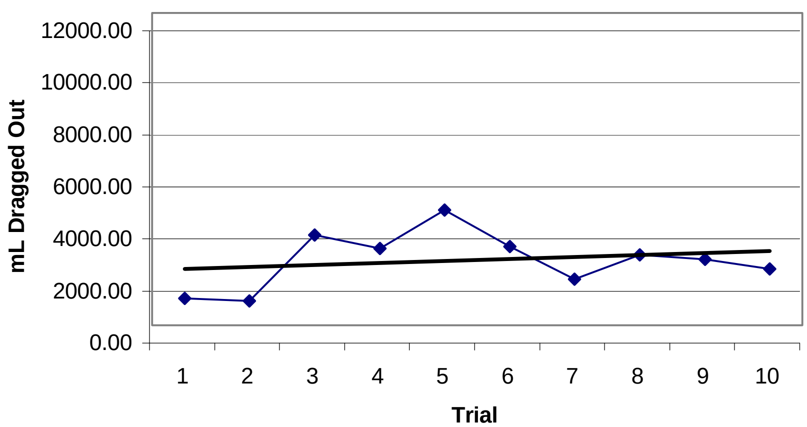


Figure A-15 - Graphed Raw Dragout Data - Barrel Design 5 - Trial 3

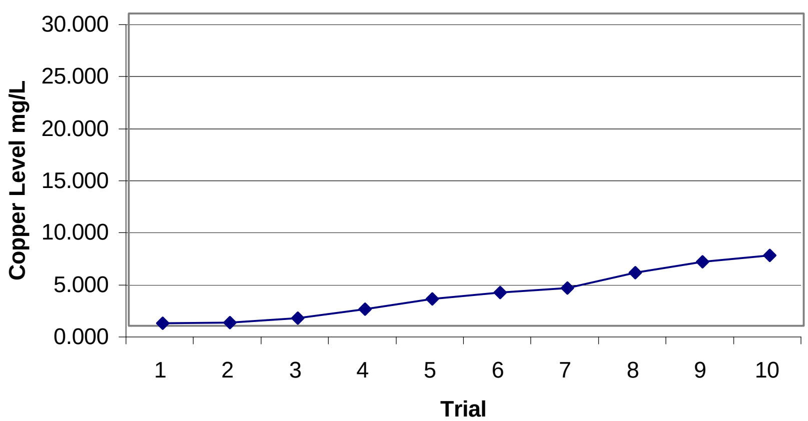
Results **Trial #3** **Barrel Design #5**

653.3

Sample No.	**Results Copper mg/L**	**Volume of Solution Dragged Out in mL**
Initial	209.00	------------
Final	195.00	------------
Blank	0.053	------------
#1	0.249	612.664
#2	0.324	234.438
#3	0.742	1306.600
#4	1.610	2713.227
#5	2.610	3125.837
#6	3.190	1812.986
#7	3.600	1281.593
#8	5.080	4626.239
#9	6.150	3344.646
#10	6.770	1938.019
		2099.62

ml dragged out per lbs/parts

13.9975



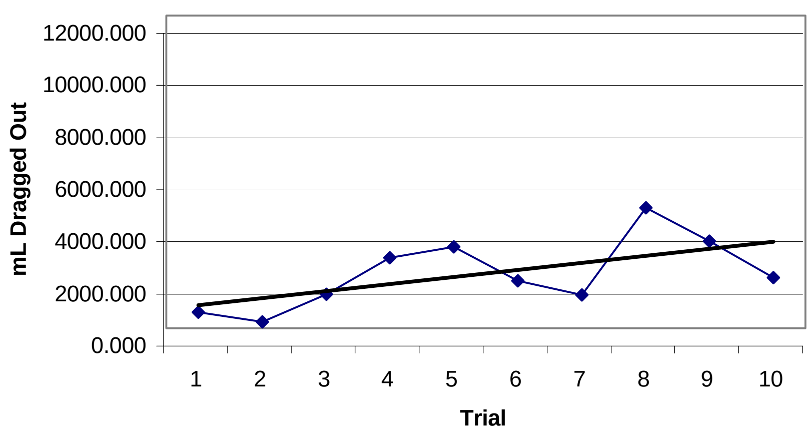


Figure A-16 - Graphed Raw Dragout Data - Barrel Design 6 - Trial 1

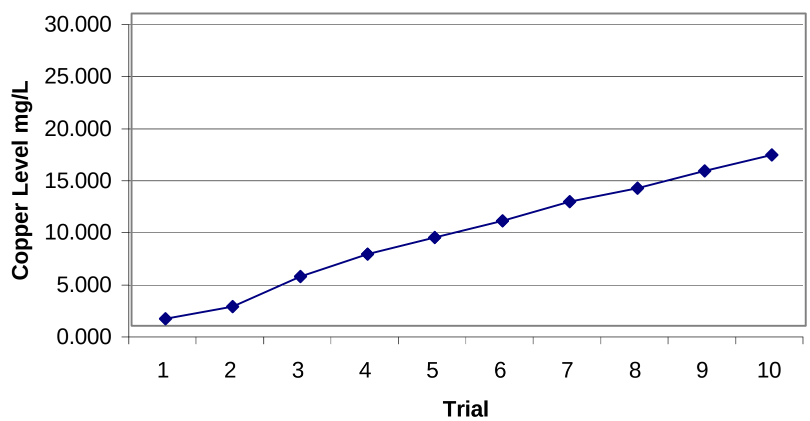
Results **Trial #1** **Barrel Design #6**

653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	363.00	------------
Final	329.00	------------
Blank	0.198	------------
#1	0.668	845.871
#2	1.830	2091.280
#3	4.750	5255.196
#4	6.890	3851.410
#5	8.470	2843.565
#6	10.100	2933.551
#7	11.900	3239.504
#8	13.200	2339.642
#9	14.900	3059.532
#10	16.400	2699.587
		2915.91

ml dragged out per lbs/parts

19.43942



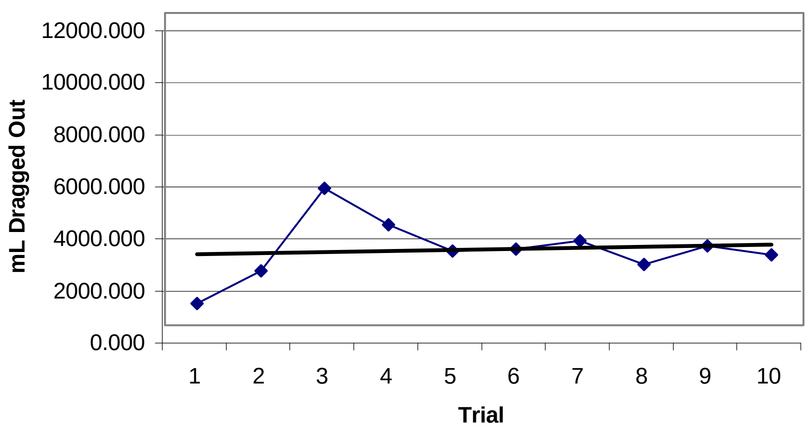


Figure A-17 - Graphed Raw Dragout Data - Barrel Design 6 - Trial 2

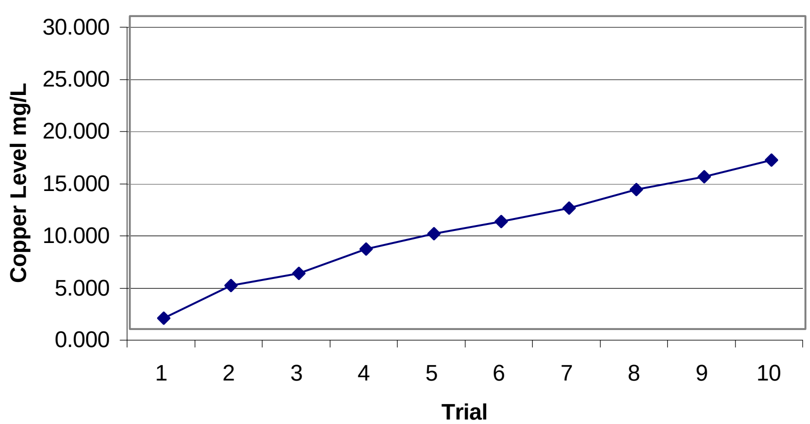
Results **Trial #2** **Barrel Design #6**

653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	343.00	------------
Final	346.00	------------
Blank	0.799	------------
#1	1.070	516.164
#2	4.200	5961.601
#3	5.330	2152.271
#4	7.670	4456.915
#5	9.120	2761.764
#6	10.300	2247.504
#7	11.600	2476.064
#8	13.400	3428.397
#9	14.600	2285.598
#10	16.200	3047.464
		2933.37

ml dragged out per lbs/parts

19.55583



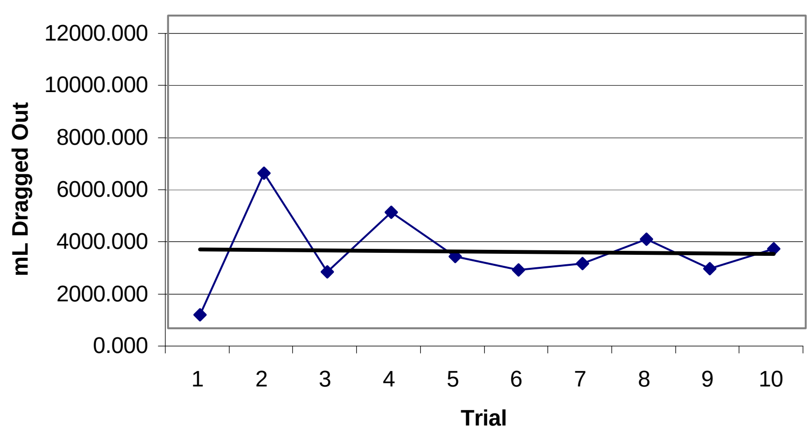


Figure A-18 - Graphed Raw Dragout Data - Barrel Design 6 - Trial 3

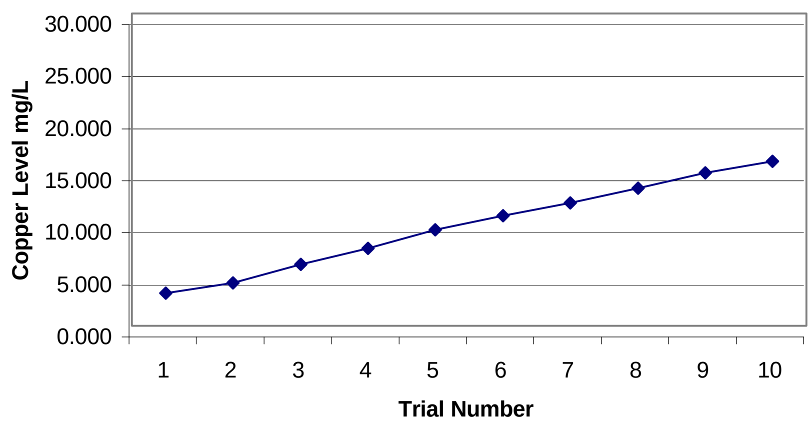
Results **Trial #3** **Barrel Design #6**

653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	318.00	------------
Final	286.00	------------
Blank	0.665	------------
#1	3.140	5084.646
#2	4.140	2054.403
#3	5.890	3595.204
#4	7.430	3163.780
#5	9.200	3636.292
#6	10.600	2876.164
#7	11.800	2465.283
#8	13.200	2876.164
#9	14.700	3081.604
#10	15.800	2259.843
		3109.34

ml dragged out per lbs/parts

20.72892



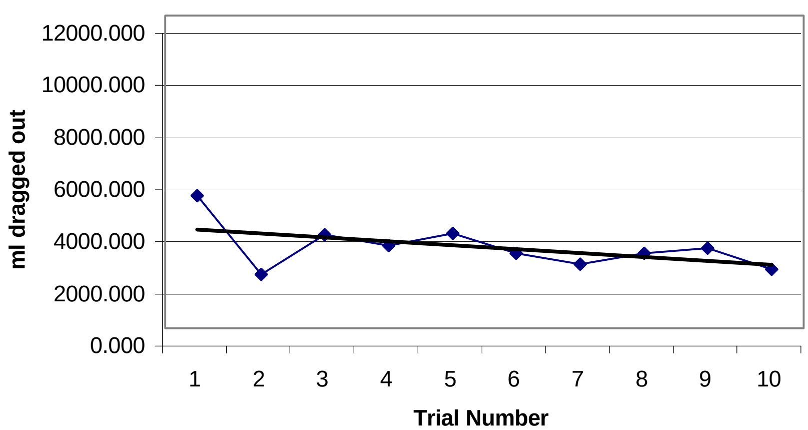


Figure A-19 - Graphed Raw Dragout Data - Barrel Design 7 - Trial 1

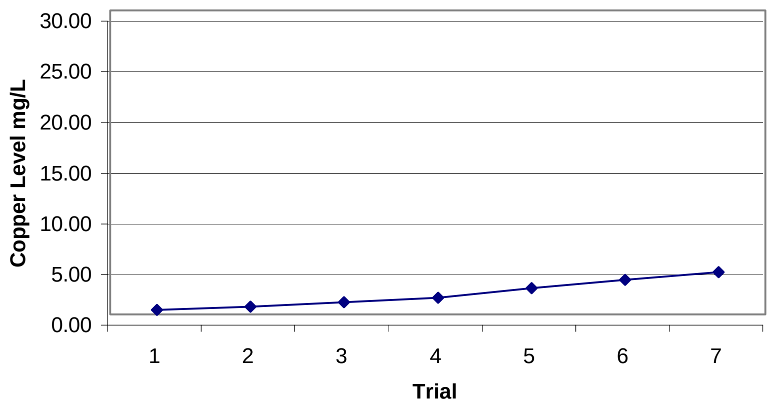
Results **Trial #1** **Barrel Design #7**

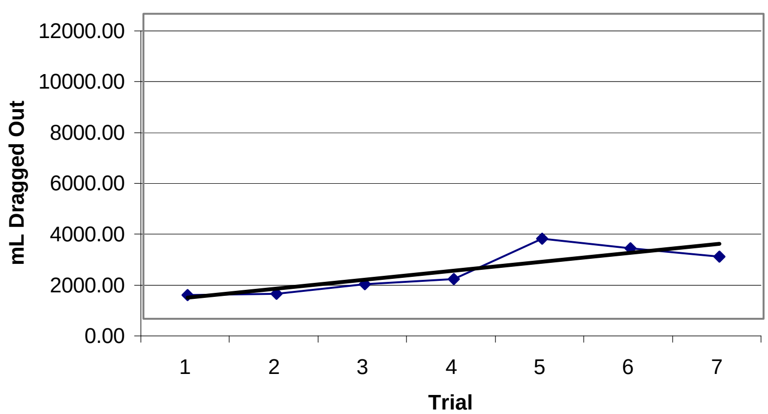
653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	
Initial	197.00	------------	
Final	186.00	------------	
Blank	0.18	------------	
#1	0.46	928.55	
#2	0.76	994.87	
#3	1.17	1359.66	
#4	1.64	1558.63	
#5	2.59	3150.43	
#6	3.43	2785.64	
#7	4.17	2454.02	
#8	8.24	13497.11	**
#9	8.76	1724.45	**
#10	10.30	5107.02	**
		1890.26	*

ml dragged out per lbs/parts

12.60173 ***





* Based on Samples 1-7

** Not Included in Averages or on Graphs

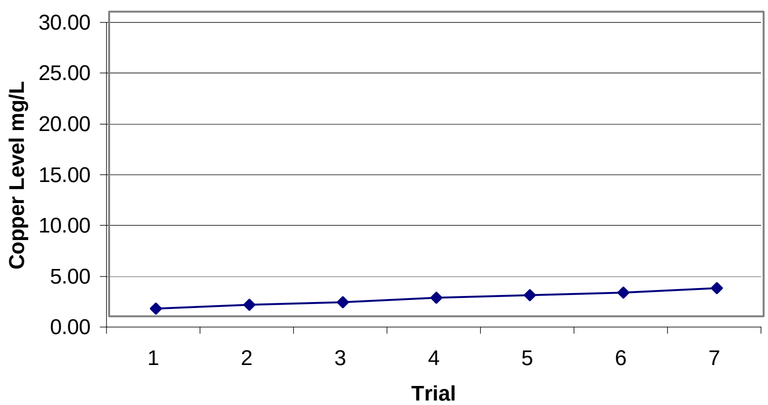
*** Does Not Include Samples 8-10

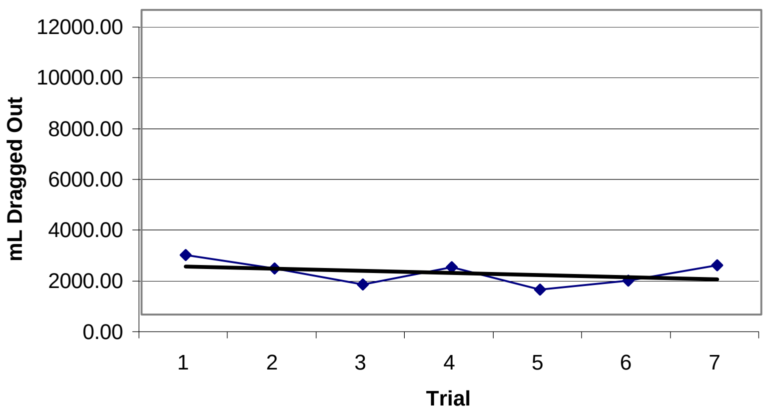
Figure A-20 - Graphed Raw Dragout Data - Barrel Design 7 - Trial 2

Results **Trial #2** **Barrel Design #7**

653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	148.00	------------	
Final	141.00	------------	10.88833 ***
Blank	0.20	------------	
#1	0.73	2339.52	
#2	1.14	1809.82	
#3	1.41	1191.83	
#4	1.83	1853.96	
#5	2.05	971.12	
#6	2.35	1324.26	
#7	2.79	1942.24	
#8	6.24	15228.95 **	
#9	9.21	13110.14 **	
#10	12.70	15405.52 **	
		1633.25 *	





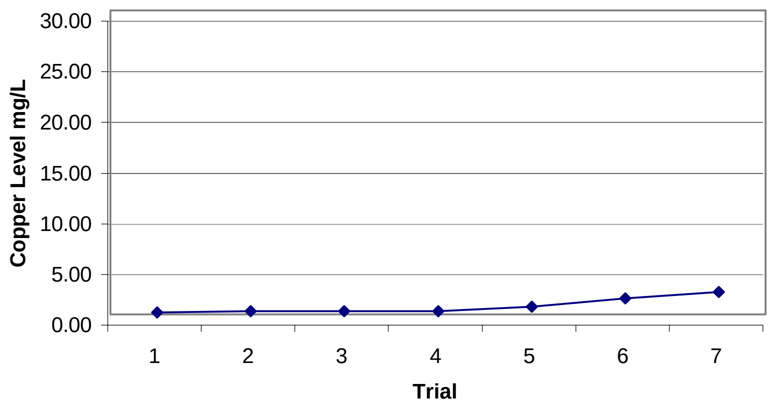
* Based on Samples 1-7
** Not Included in Averages or on Graphs
*** Does Not Include Samples 8-10

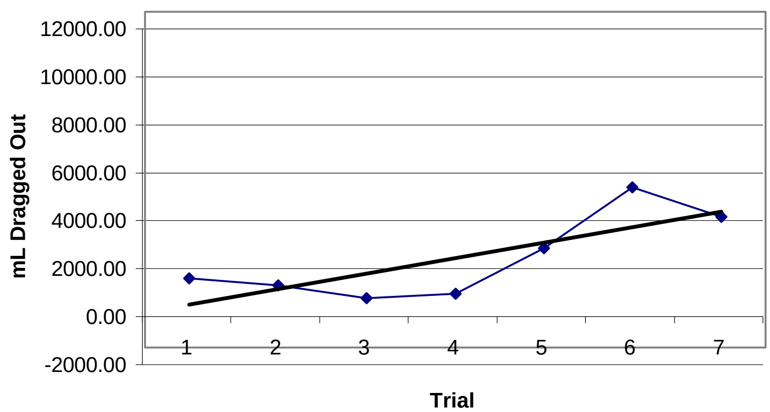
Figure A-21 - Graphed Raw Dragout Data - Barrel Design 7 - Trial 3

Results **Trial #3** **Barrel Design #7**

653.3

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL	ml dragged out per lbs/parts
Initial	117.00	------------	
Final	108.00	------------	11.5185 ***
Blank	0.02	------------	
#1	0.18	893.40	
#2	0.29	591.88	
#3	0.30	61.42	
#4	0.35	256.85	
#5	0.73	2138.58	
#6	1.57	4690.36	
#7	2.19	3461.93	
#8	8.00	32441.65 **	
#9	9.00	5583.76 **	
#10	10.00	5583.76 **	
		1727.78 *	





* Based on Samples 1-7
** Not Included in Averages or on Graphs
*** Does Not Include Samples 8-10

Figure A-22 - Graphed Raw Dragout Data - Barrel Design 8 - Trial 1

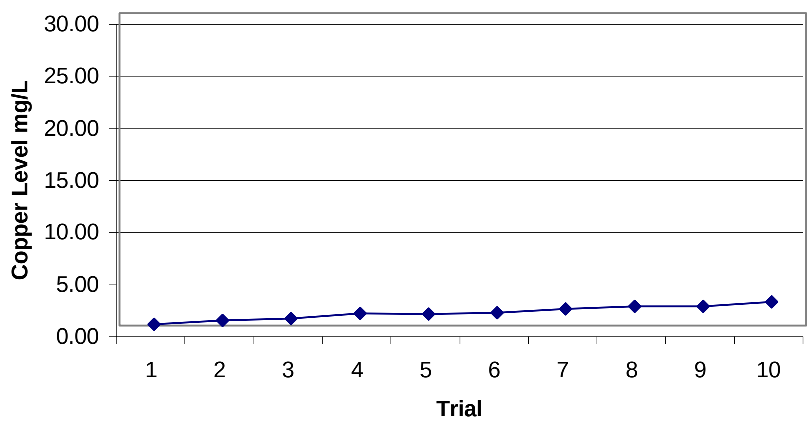
Results **Trial #1** **Barrel Design #8**

804.5

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	131.00	------------
Final	128.00	------------
Blank	0.00	------------
#1	0.13	798.36
#2	0.47	2088.02
#3	0.66	1166.83
#4	1.16	3070.61
#5	1.12	-245.65
#6	1.20	491.30
#7	1.57	2272.25
#8	1.84	1658.13
#9	1.82	-122.82
#10	2.27	2763.55
		1394.06

ml dragged out per lbs/parts

9.293715



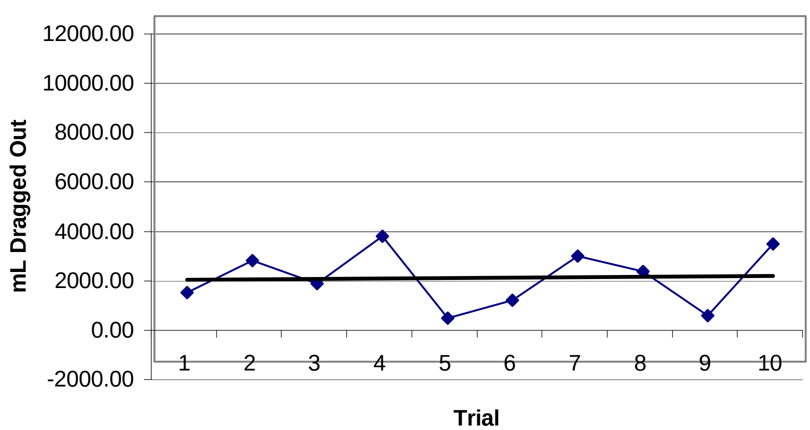


Figure A-23 - Graphed Raw Dragout Data - Barrel Design 8 - Trial 2

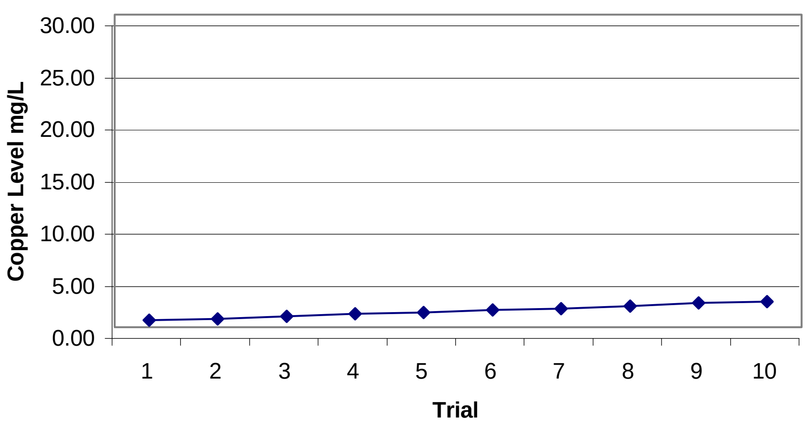
Results **Trial #2** **Barrel Design #8**

804.5

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	130.00	------------
Final	121.00	------------
Blank	0.27	------------
#1	0.65	2351.62
#2	0.79	866.38
#3	1.04	1547.12
#4	1.26	1361.46
#5	1.43	1052.04
#6	1.65	1361.46
#7	1.79	866.38
#8	2.01	1361.46
#9	2.31	1856.54
#10	2.43	742.62
		1336.71

ml dragged out per lbs/parts

8.911385



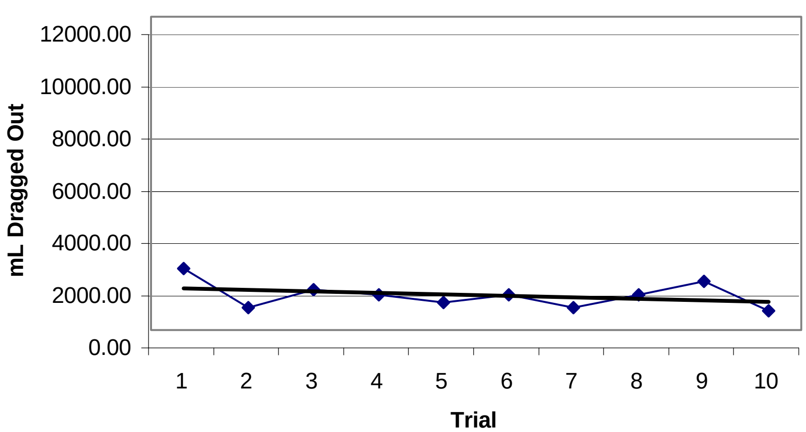


Figure A-24 - Graphed Raw Dragout Data - Barrel Design 8 - Trial 3

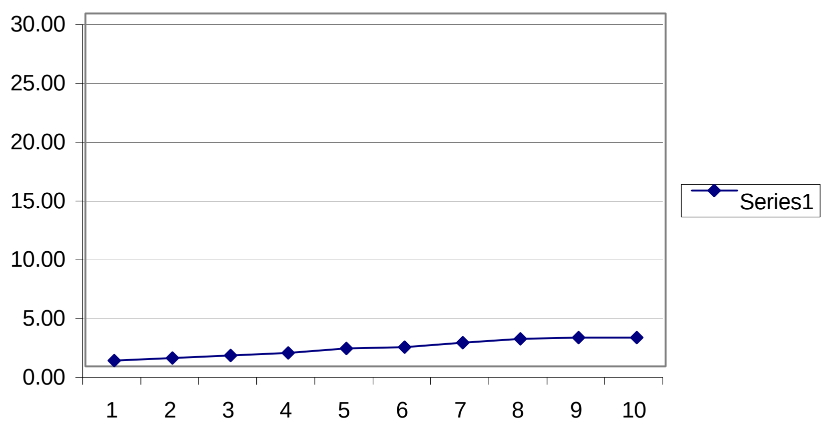
Results **Trial #3** **Barrel Design #8**

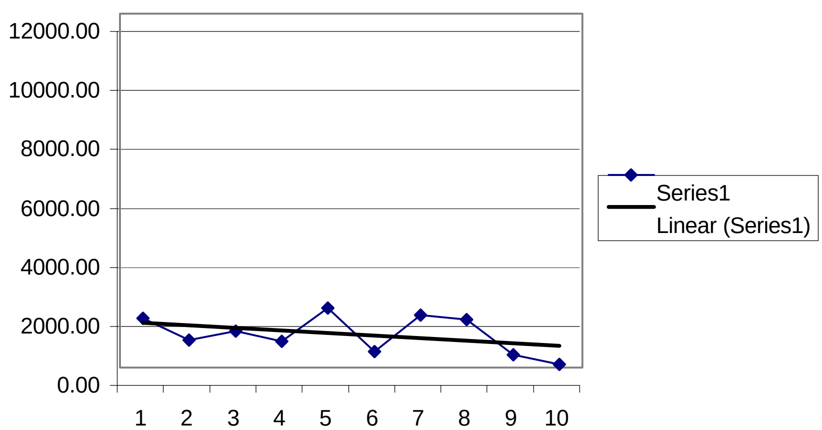
804.5

Sample No.	Results Copper mg/L	Volume of Solution Dragged Out in mL
Initial	163.00	------------
Final	144.00	------------
Blank	0.17	------------
#1	0.51	1678.10
#2	0.70	937.76
#3	0.95	1233.90
#4	1.13	888.40
#5	1.54	2023.59
#6	1.65	542.91
#7	2.01	1776.81
#8	2.34	1628.74
#9	2.43	444.20
#10	2.45	98.71
		1125.31

ml dragged out per lbs/parts

7.502086





Appendices

Appendix B: Photographs of Tested Barrels

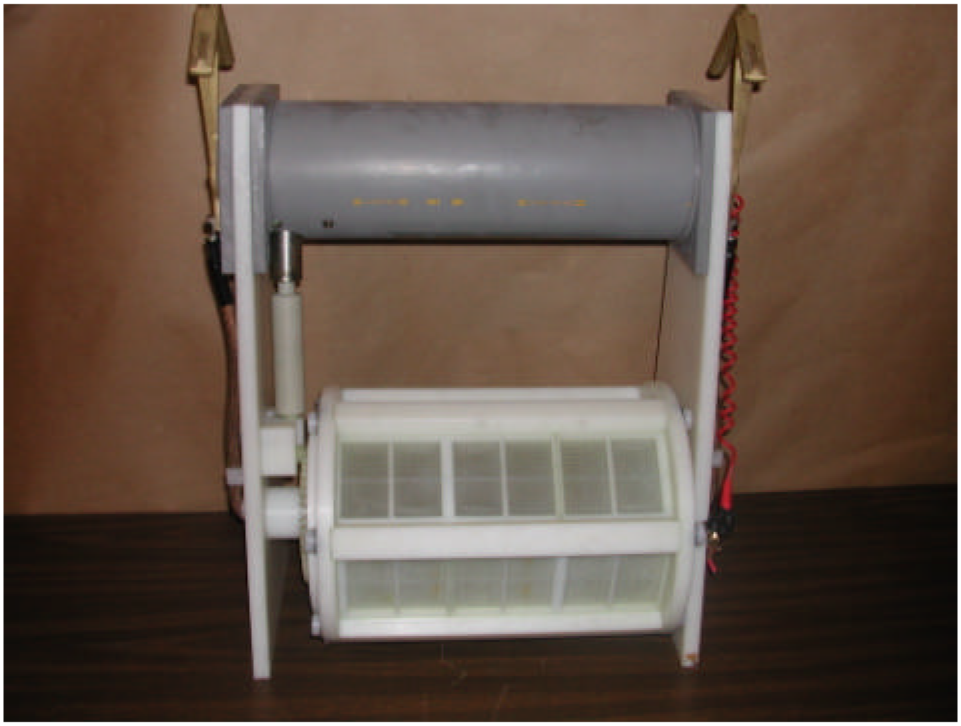


Figure C-1

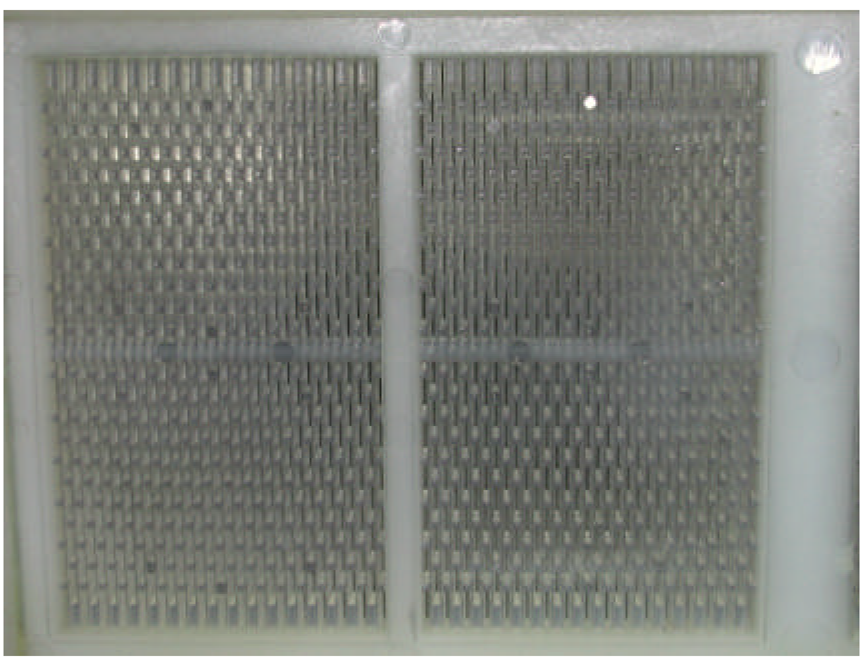


Figure C-2

Figure C-3

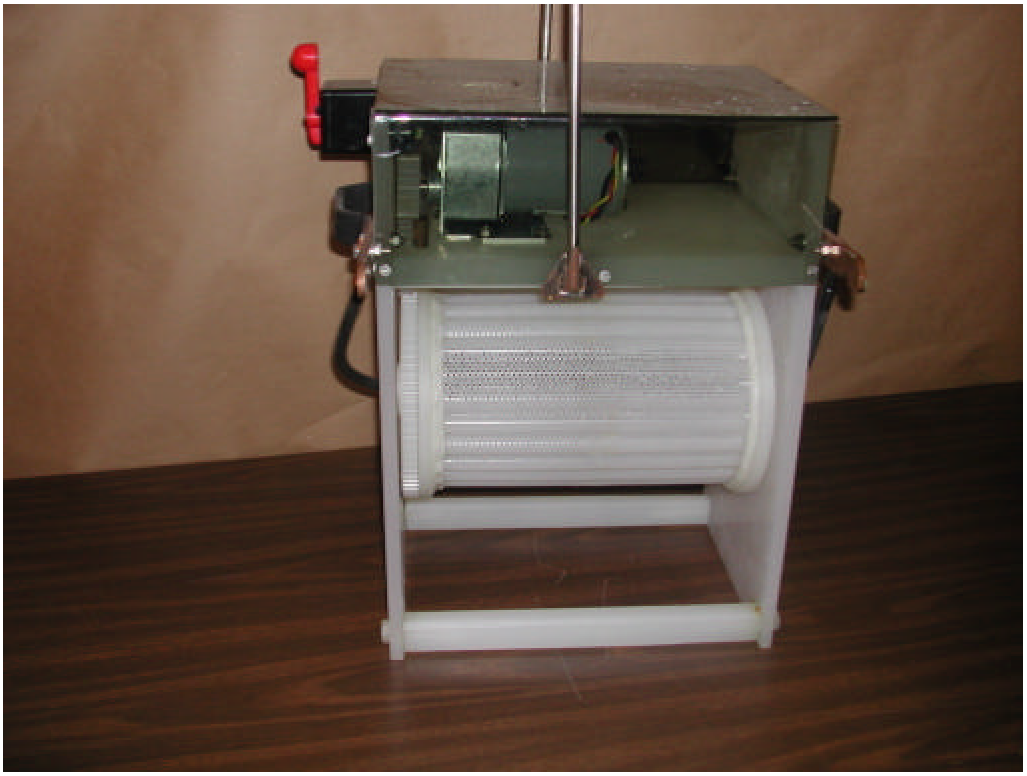


Figure C-4

Figure C-5

Figure C-6

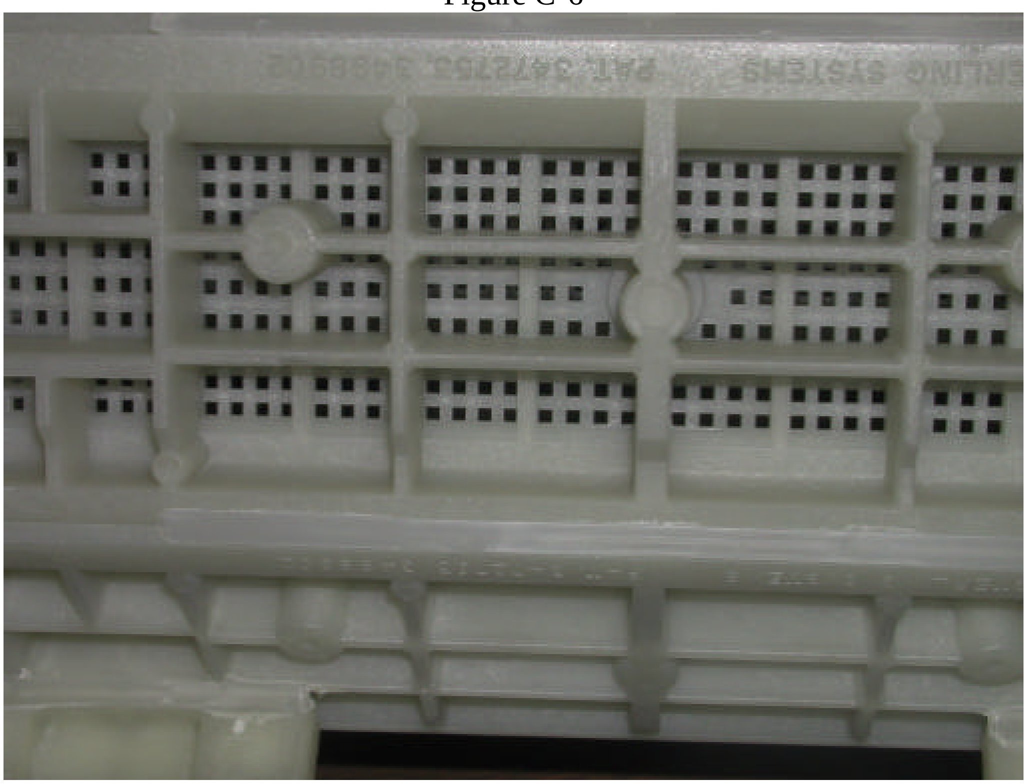


Figure C-7

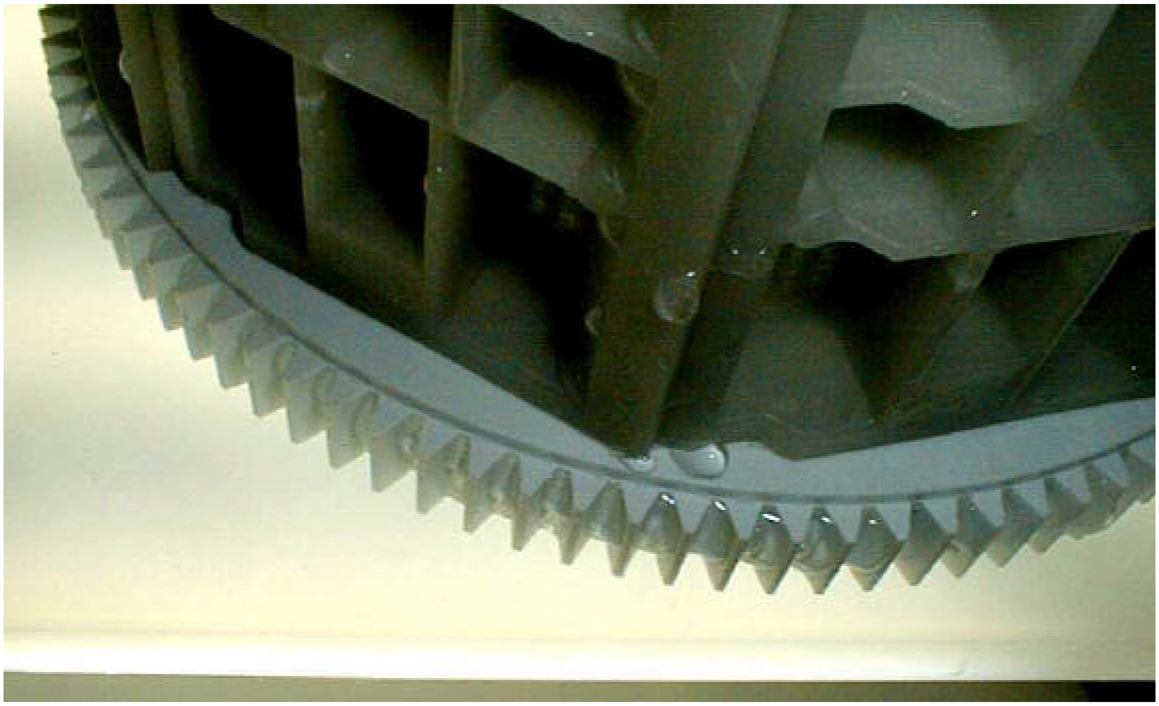


Figure C-8

Figure C-9

Figure C-10

Figure C-11

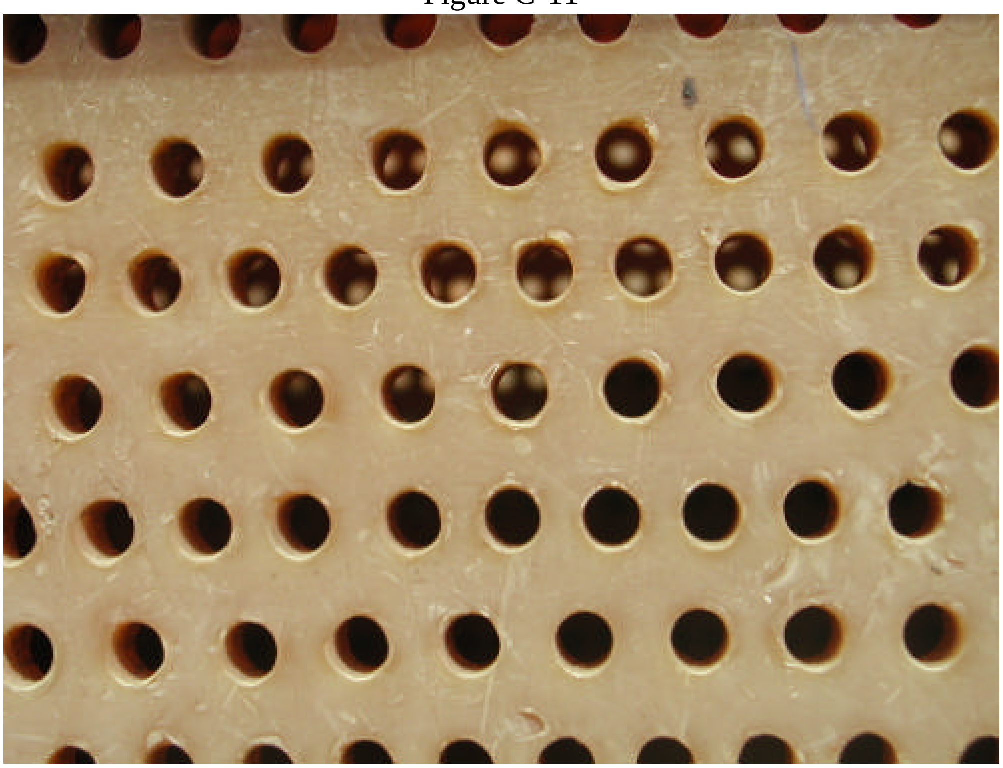


Figure C-12

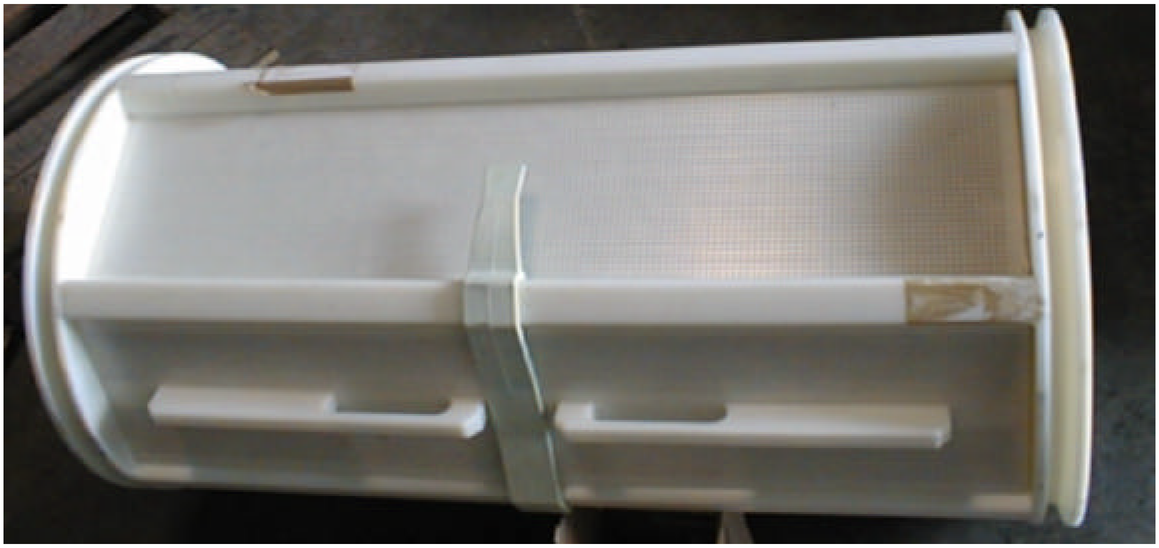


Figure C-13

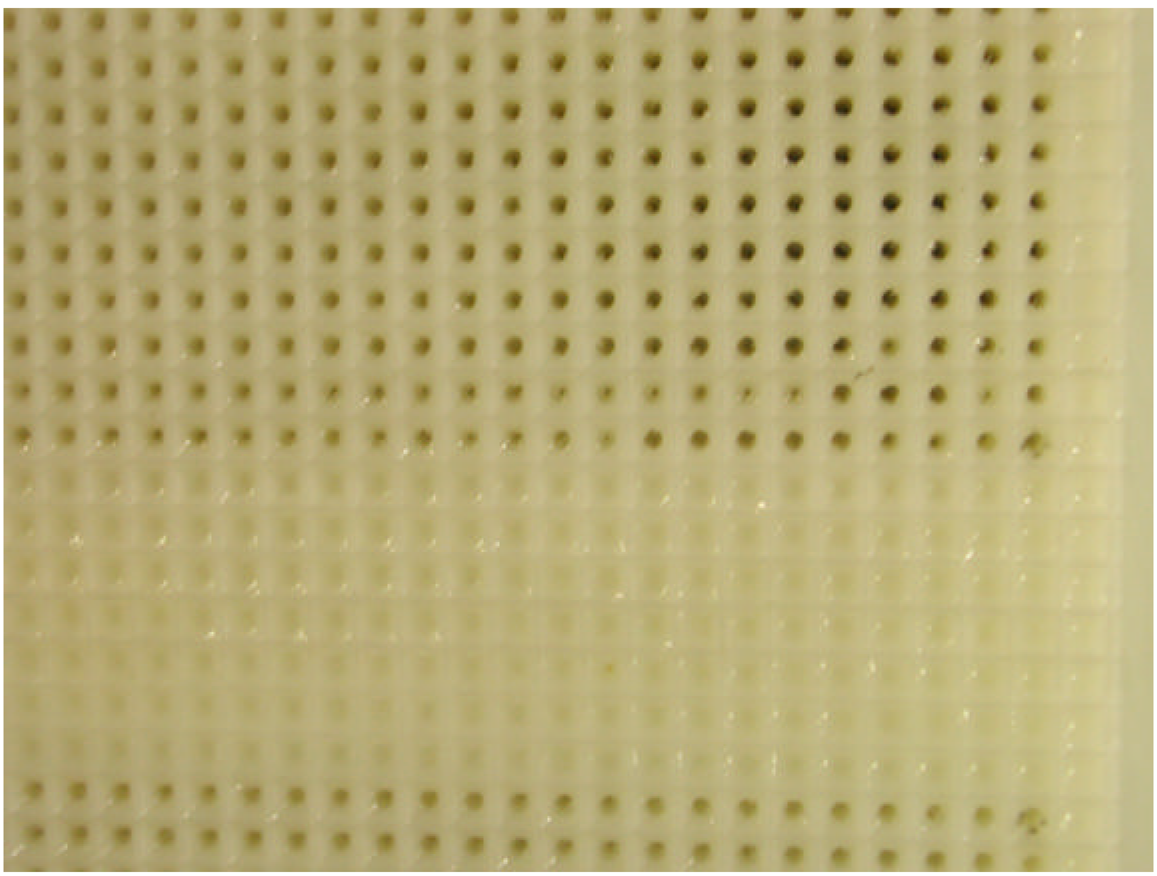


Figure C-14

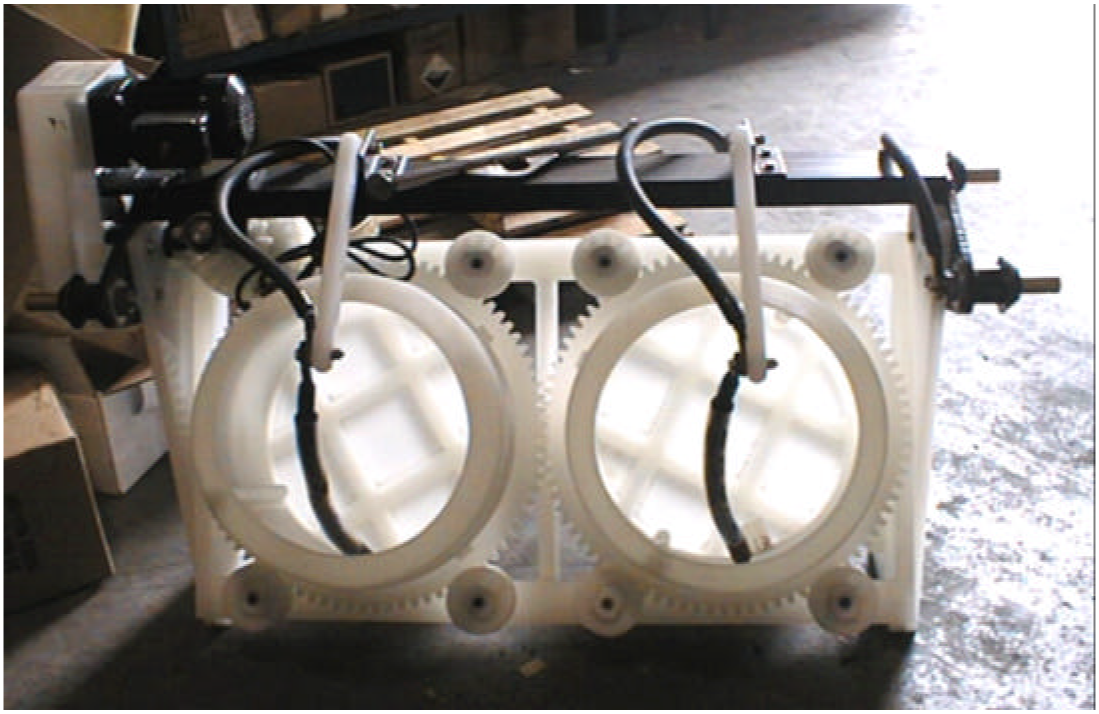


Figure C-15

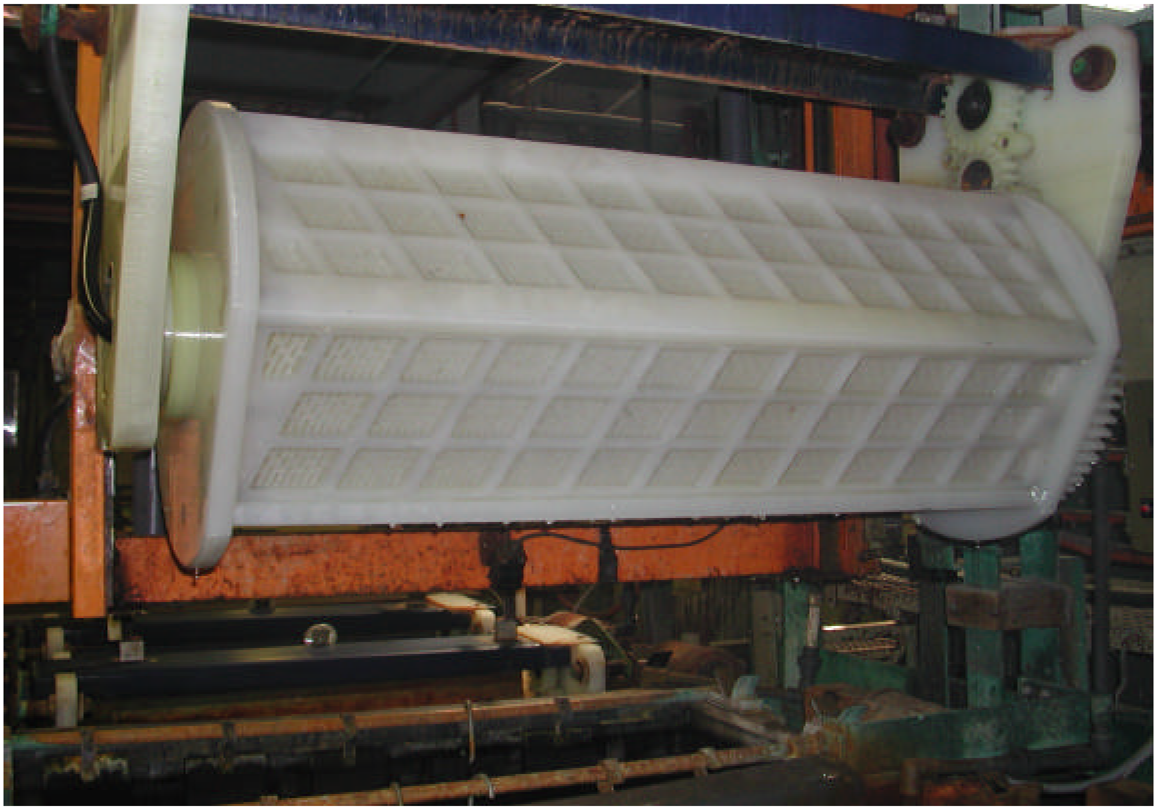


Figure C-16

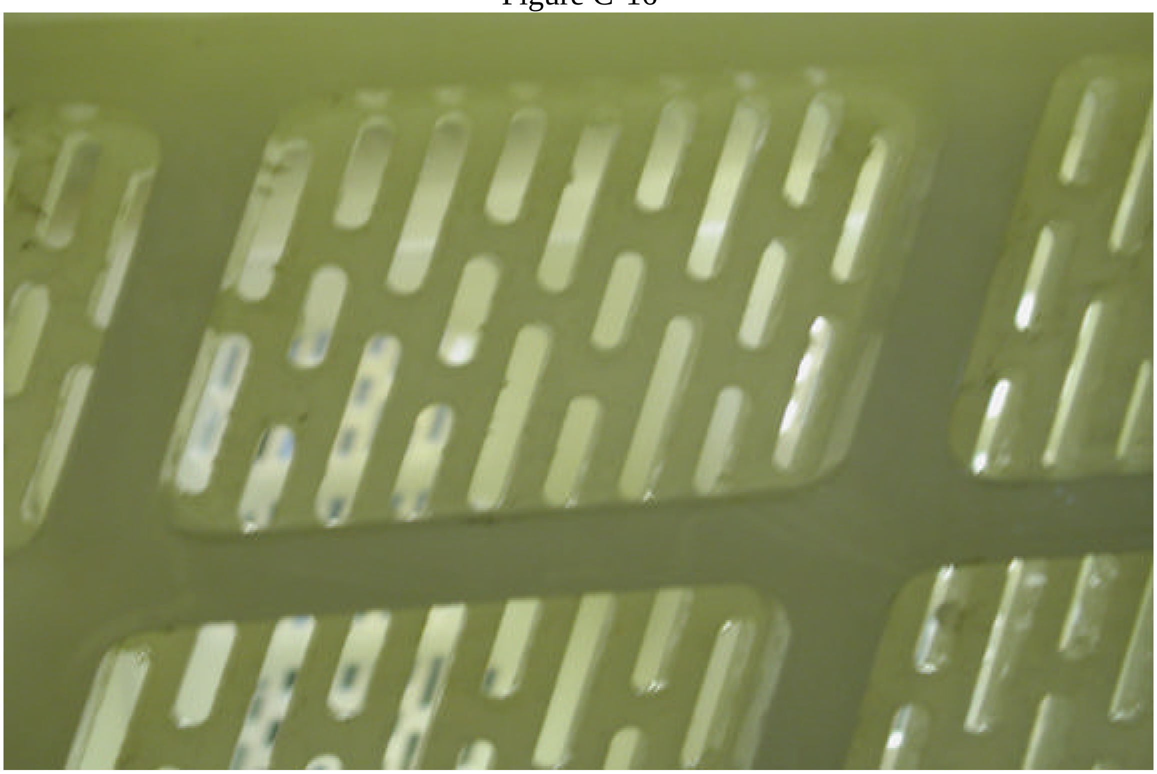


Figure C-17

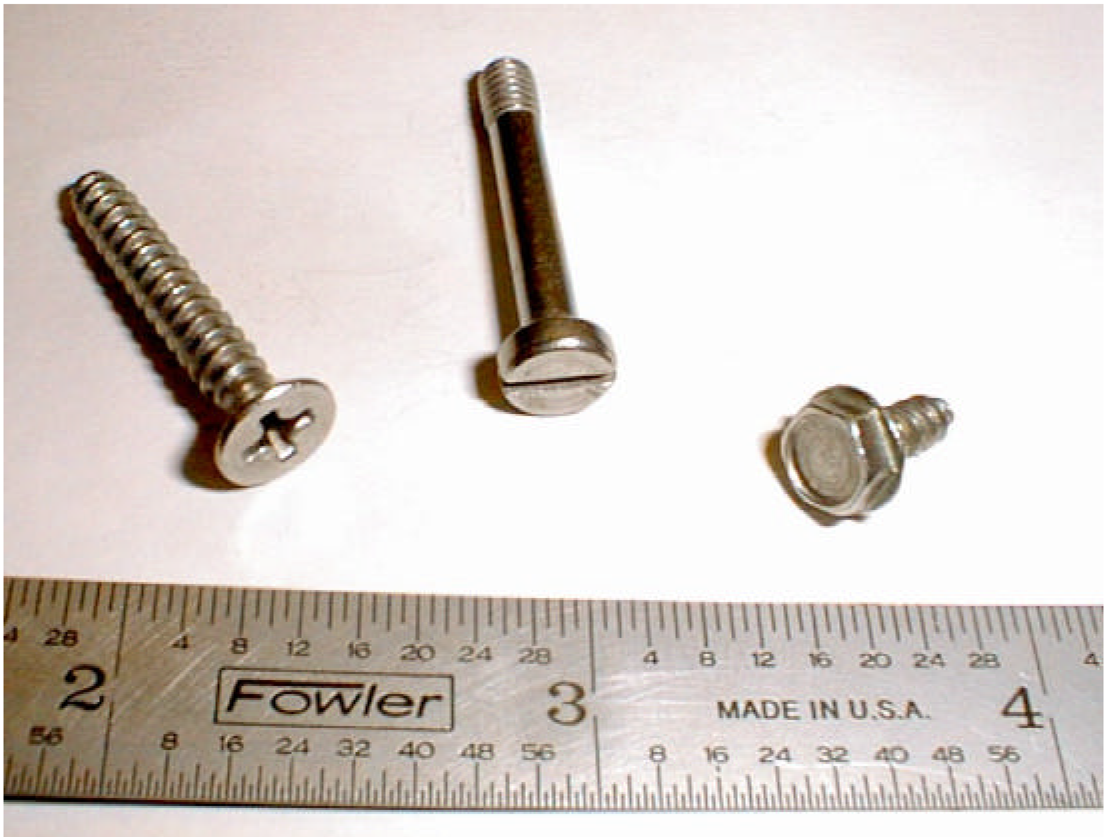


Figure C-18

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