Eductor Agitation for a Nickel Electroplating Installation

*by C. Porter & D.R. Gabe**

The design, installation and optimization of an eductor agitation system for a 6000-L (~1600-gal) nickel tank is described and its performance measured against the formerly used air agitation system. A total of 20 eductors were installed, five eductors per side. Eductors on two opposite sides were inclined at 30° from the horizontal and the other two sides at 60°. Agitation enhancement factors of 7 to 10X were measured, giving 36% deposition rate improvement and shorter process times (71% improvement). Reduction in nickel thickness variability (i.e., edge build-up) of up to 92% was measured. Metal / acid fumes were virtually reduced to zero emission.

Since the earliest days of electroplating in the 1840s, agitation has been recognized as one of the core process parameters and the means of agitation a vital piece of its process hardware. The purposes of agitation have been rehearsed several times[1,2] where it has been pointed out that while air is cheap and simple it is by no means the best and can have quite serious drawbacks, *e.g.*, oxidation of solution constituents, loss of solution conductivity and cooling of solution.

During the last ten years the use of solution pump jetting, notably through eductor nozzles, has received much interest and several suppliers have been active in the market place. The perceived marketing features include focused agitation towards the workpiece and the bonus of Venturi nozzles in which one volume is pumped and five volumes are ejected. However, several additional features are now recognized as possibly more important characteristics:

- No oxidation of solution constituents by an agitating gas
- No loss of solution conductivity
- No fumes except from gas evolution at the electrodes.

It should be noted that the electrode effects of generating either hydrogen or oxygen are trivial when compared to the volumes of air used in agitation but the effect of insoluble "catalytic" anodes in promoting constituent oxidation is clearly a separate matter.

In principle, eductor agitation can be used for electroplating, anodizing, cleaning, pickling and rinsing, although the only scientific studies relate to the first two.[3-9] The previous electroplating studies[3-7] have been reported in the context of copper deposition on printed circuit board (PCB) production which represents a special case. This paper reports on an installation for nickel plating, using racks and explores:

- Design of the eductor agitation installation
- Performance and optimization for deposit thickness distribution
- Fume measurement and control.

Eductor system design

General specification

The existing tank was 1.8 × 1.8 × 1.8 m (5.9 × 5.9 × 5.9 ft) with a working capacity of 6000 L (1585 gal). A temporary pumped ring mains was to be submerged around the bottom perimeter leaving the air sparge tubes in place. Filtration was kept as a separate pumped circuit. Agitation at 40 turnovers/hr was specified, which meant an agitation flow rate of 4000 L/min** (1057 gal/min), of which 20% is pumped and 80% venture-induced. Thus the total pumped volume is 800 L/min (211 gal/min) for which a 2.2-kW (2.95-hp), three-phase, 415-V pump was required.

Nuts & Bolts: What This Paper Means to You

This paper discusses the use of eductor nozzles, a significant means of improved solution agitation. They make possible focused agitation toward the parts, and the Venturi principle actually multiplies the volume of solution that is pumped. Further, solution oxidation and fuming (except for the usual gas evolution at the electrodes) are largely eliminated. The authors present data from experiences with eductors in an actual plating installation.

* *Corresponding Author*
Dr. David R. Gabe
Institute of Polymer Technology and Materials Engineering, Loughborough University
Loughborough, Leicestershire, LE11 3TU, UK
E-mail: D.R.Gabe@lboro.ac.uk

** *6000 L × 40 turnovers / 60 min = 4000 L/min.*

Eductor numbers

The total eductor input was shown above to be 800 L/min (211 gal/min). Using 3/8-in. eductors at 10.7 m (35 ft) total dynamic head, charts indicate a nozzle flow of 41.8 L/min (11 gal/min) which leads to a requirement of 800/41.8 = 19.14 eductor nozzles which for practical symmetry means 20 total or four banks of five. It was proposed that each tank side would have five eductors whose angle of ejection could be altered using a swivel feed tube. The pump and eductors are commercially available.***

System costing

The costing base was £ sterling in 2002****, tank included. Fitting and assembly was done by regular staff at no direct charge. The main components of external cost were:

2.2-kW (2.95-hp) pump and
20 3/8-in. eductors .... £1652 (~US $3120)****

PVC pipework (1.5 and 2 in.), bushes,
elbows, tees, valves...£466 (~US $880)

Electrical connections, re-wiring
of heaters, etc .... £391 (~US $740)

Total .... £2509 (~US $4740)

Additional down-time, emptying of the tank and rinsing were not separately costed. However, it should be noted that failure to clean the tank walls thoroughly by scrubbing led to serious overloading of the filtration circuit because the more abrasive agitation produced by the eductors caused substantial spalling over a period of several weeks, giving rise to excess debris being produced. A future installation should always use a new or well-cleaned and scraped tank.

Commissioning

The agitation pattern was first observed using clean water. The flow patterns could be seen but could be enhanced for clearer vision by bleeding in air to the solution feed line which led to a bubble plume. This was an important step because most plating solutions are too deep in color for detailed observations to be made and the plume cannot be seen or photographed for record and analysis purposes.

Eductor agitation operation

Benchmarking performance

The basis of performance was to use well-established air agitation practice as a benchmark for comparisons. Furthermore, before commercial work was plated, test panels were used to establish performance. These panels were 22.9 × 12.7 × ~1 cm (9 × 5 × 3/8 in.) low carbon steel flat stock, stamped for identification. Nickel thicknesses were measured by micrometer as the thickness range was typically 0.05 to 0.23 mm (0.002 to 0.009 in.), giving a weight gain of ~20 g (0.7 oz) over 5 hr of plating, this being a common requirement in the production schedules for this plant.

Surface preparation followed standard schedules as follows:

- Weigh each panel and attach wire rack connection.
- Vapor degrease in trichloroethylene.
- Submerge in wax tank for masking.
- Knife removal of wax for exposed area.
- Etch in sulfuric acid for 5 min at 7.5 V.
- Nickel strike for 5 min at 5.0 V.
- Nickel electroplate for 5.5 hr at 1.5 V and 4 A.
- Rinse and vapor degrease to remove solution and wax.
- Separate panel for testing.

The basis of benchmarking the existing air agitation was to follow the above procedure. Deposit thicknesses were measured at 15 defined positions and the panel was weighed using electronic scales prior to and after the electroplating operation. For sample thickness testing, the panel was divided into a 5 × 3 grid, the grid being numbered 1 thru 5, 6 thru 10 and 11 thru 15 along the long side; thus reading positions 1, 5, 11 and 15 were corners and 7, 8 and 9 were central positions. From these measurements, two parameters could be determined: (1) the overall deposition rate (weight gained by the test panel), and (2) the metal thickness distribution variance. These parameters could be similarly determined for the eductor agitation system.

Eductor optimization

The eductor flow circuit consisted of a square plan ring main containing 20 eductors, five eductors per side of the tank. As originally installed, the eductor angles were set at 30° to the horizontal. However, in an attempt to increase the depth of the agitation envelope within the plating solution, it was preferred to adjust two opposite sides to 60° while retaining the others at 30°. This is shown in Fig. 1.

This format was considered to be optimal although a case can be made for having a central eductor on two opposite sides angled horizontally to ensure no stagnation at the bottom. This would also keep all precipitation moving for eventual removal in the filtration circuit. The same procedure as for air agitation was used to determine deposition rates and metal distribution variance.

Airborne emissions

A standard Draeger tube device was used to measure the fume emissions, where the glass vials develop color changes. The accuracy is claimed to be ±10%. The vials are stable if stored out of

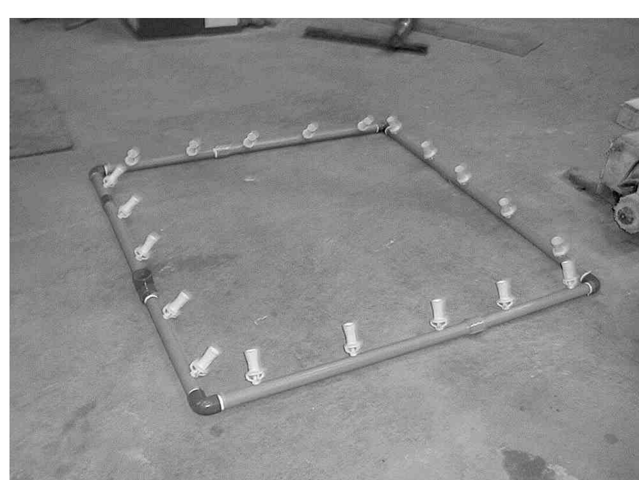

Figure 1—The square plan ring mains before being placed in the tank.

*** *Serductors, Serfilco Europe, Ltd., Manchester, UK; Serfilco Ltd., Northbrook, IL.*

**** *£1.00=US $1.89 as of March 2005.*

sunlight at 25°C (77°F), and they are easy to operate and read. A standard nickel sensitive tube was used having a measuring range of 0.25 to 1.0 mg/m^3. It utilizes the HCl-solubility of nickel and a dioxime indicator which turns pink.

Results

Deposition rates

A deposition time of 5.5 hr was used for the rate tests. This corresponded to some standard production schedules for which the agitation system was being devised. Typical test piece weight gains are shown in Table 1. This represents an increase in deposition rate of 22% and 36.3%, respectively.

Deposit thickness variance

A total of 15 thickness measurements were taken for each test panel. For air agitation, the results showed a 0.20-mm (0.008-in.) variation in deposit thickness. Using a standard positioning code, the results are given in Fig. 2. Positions 1, 5, 11 and 15, represent the four corners and positions 7, 8 and 9 represent the central portion of the test panel. On this graph the horizontal line at 0.374 in. represents the test piece thickness as baseline.

The procedure was repeated for the two eductor agitation formats, and the results are shown in Figs. 3 and 4. Using all eductors at 30° the variation was 0.15 mm (0.006 in.) and for the 30° and 60° configurations the variation was 0.08 mm (0.003 in.). Clearly the thickness variation was substantially reduced and a comparison of the air agitation with the optimized eductors is very marked, as shown in Fig. 5.

Table 1
Typical weight gain obtained by each agitation mode

Agitation Mode	Weight gain, g (oz)	Deposition rate, g/hr
Air	20.4 (0.72)	3.709
Eductor (all 30°)	24.9 (0.88)	4.527
Eductor (opposites 30° and 60°)	27.8 (0.98)	5.054

The increase of thickness by comparison with the baseline is also significant and indicates a marked increase in the agitation envelope in solution, which leads to the increased deposition rates reported.

Airborne emissions

Draeger tube measurements were made under each agitation regime. The results for air agitation show a measurement of airborne emissions of 0.5 to 1.0 mg/m^3. The use of eductor agitation reduced the airborne emissions to zero. The claim in the trade and published literature is for a reduction of over 90%. Clearly this was borne out in this investigation.

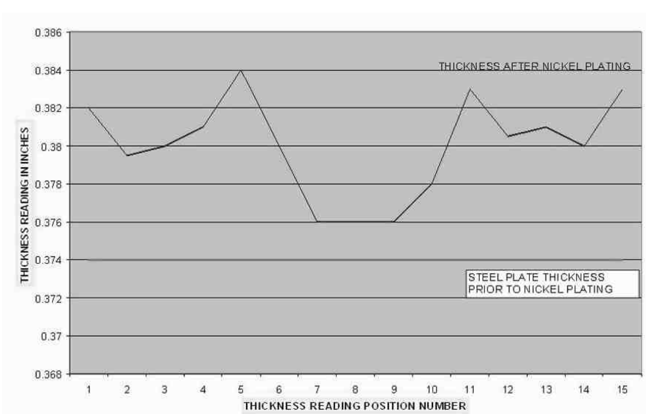

Figure 2—Thickness variation for air agitated nickel plating.

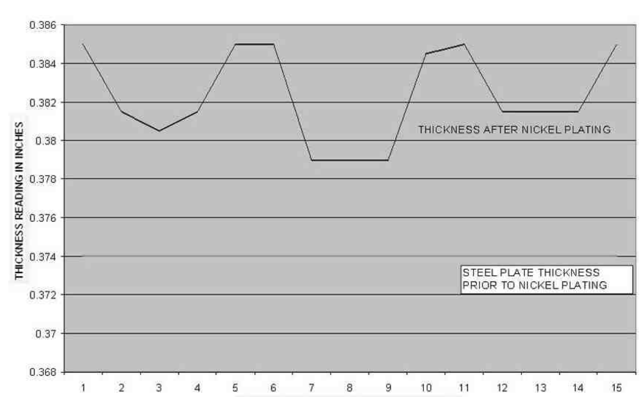

Figure 3—Thickness variation for eductors at 30°.

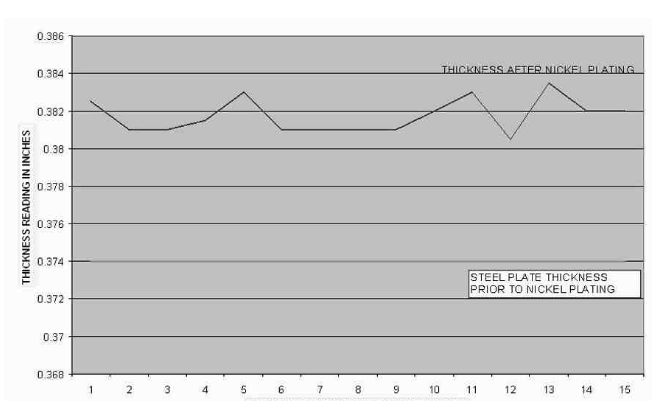

Figure 4—Thickness variation for eductors at 30 and 60°.

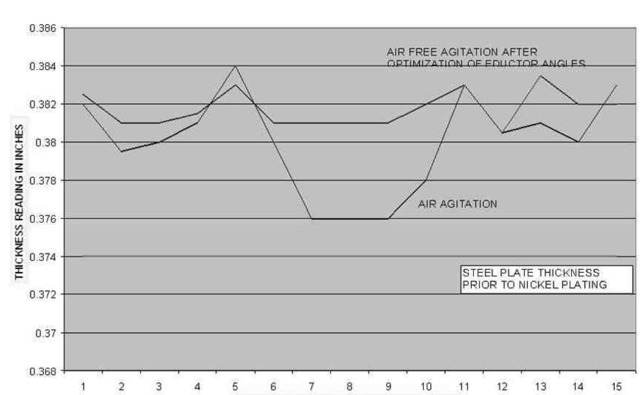

Figure 5—Comparison of thickness variations for air and optimal eductor agitation.

Observations of a qualitative nature undoubtedly indicated almost total elimination of noxious chemical fumes. Further, there was little or no frothing or foaming with the eductor agitation. The consequent saving in heat and evaporative losses was apparent but has not been measured quantitatively to date. The impact on the plant environment and corrosion of surrounding facilities will be noted on a long-term basis.

Discussion and conclusions

Thickness and rate enhancement.

The improved process performance has been self-evident from the results but can be summarized by examining the data shown in Table 2. Variation of thickness across the surface has sometimes been attributed to the air hole spacing but when the work is sufficiently far away from the sparge holes, the effect is difficult to identify. From the production viewpoint, throughput times are usually the critical measures and these can be noted together with the saving in excess nickel deposited at test panel corners, as shown in Table 3.

Installation procedures

The most important step in installation was learned by experience. This was the need to appreciate that eductor agitation is significantly more vigorous than air agitation to the extent that sludge and consolidated deposits can be stirred up and spalled from tank walls after several days or weeks of operation. While good filtration can cope with such action, it is far better to include abrasive cleaning with the eductor installation. Therefore, a recommended procedure would be as follows:

- Empty tank and thoroughly wash solution residues.
- Grit blast the internal surfaces of the tank and remove debris.
- Rinse tank thoroughly.
- Install the eductor pipework and ensure that eductors can be rotated.
- Fill tank with water and visually optimize the eductor plume flow.
- Empty tank and re-fill with plating solution.
- Circulate solution through filters and commence eductor electroplating.

Localization of agitation may be avoided when the plumes are observed during commissioning. Thus work must be placed sufficiently far away from the eductors to avoid high points of agitation where adjacent plumes overlap and impact on the workpieces. This is particularly important for PCBs but less so for racked components. Because it is usual to deposit to a minimum thickness, the concern is really to reduce the spread of thickness over the whole surface.

Table 2
Weight gain and thickness summary

Criterion	Air agitation	Eductor agitation (30°)	Optimal eductors (30/60°)
Weight gain, g (oz)	20.4 (0.72)	24.9 (0.88)	27.8 (0.98)
Thickness variation, mm (in.)	0.20 (0.008)	0.15 (0.006)	0.08 (0.003)
Thickness at corners, mm (in.)	0.25 (0.010)	0.28 (0.011)	0.23 (0.009)
Thickness at panel center, mm (in.)	0.05 (0.002)	0.13 (0.005)	0.18 (0.007)

Table 3
Productivity gains summary

Agitation	Time to deposit 0.008 in.	Excess nickel at corners, mm(in.)	Reduction in time, %	Improvement in deposition, %	Improvement in waste, %
Air agitation	22 hr	0.81 (0.0320)	---	---	---
Eductor agitation	8 hr, 48 min	0.24 (0.0096)	60	22.0	70
Optimal eductors	6 hr, 17 min	0.06 (0.0023)	71	36.3	92

Bonuses of eductor usage

In this work, the advantages sought for eductor agitation were higher rates of deposition to increase plant throughput, better thickness distribution over racked work and measured reduction in fumes from the tanks. Previous reports have noted other advantages and although there is no new definitive data to substantiate these advantages the plant performance points to their importance. They include the following:

- Reduction in sludge production, as a consequence of solution constituent oxidation and filter cartridge usage,
- Reduction in plating additive consumption
- A saving of ~1.0 V on the tank voltage, for a given electroplating current, because of the increased solution conductivity in the absence of agitative air which can represent typically 25% and occasionally up to 30% by volume in the solution,
- A saving of solution heater power due to reduced cooling effects attributable to the air; estimates suggest that this could be 10 to 20%,
- A saving of fume extraction costs including pumping rates, condensate volumes and acid neutralization.

To adequately quantify these items, better instrumentation is required; for example, individual power metering on each tank bus bar current and heater circuits, and monitoring of filter cartridge accumulations. It is hoped that this may be possible in future operations. While each of these items may seem small, the total effect will be a substantial saving in process costs and materials used by reducing the over-coating tendency when responding to minimum thickness specifications. However, the undoubted advantage that has emerged is the reduction of fume emissions in the context of environmental and health requirements.

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About the Authors

Clive Porter is currently Technical Sales Manager at Weir Engineering Services Ltd., Grays, Essex, UK. Between 1989 and 2005, he held a variety of positions at Dowding & Mills Engineering Services. In 2003 he earned a M. Sc. degree in Surface Design and Engineering at Nottingham University. His final year project dissertation "Air Free Agitation of Electroplated Nickel," was supervised by Professor David Gabe of Loughborough University.

Dr. David R. Gabe is Emeritus Professor of Materials Engineering at Loughborough University of Technology, Leics., England, and formerly director of the Institute for Polymer Technology and Materials Engineering. He is a graduate of the University of Wales (Cardiff) and received a PhD from the University of Sheffield. He has published more than 250 papers on electrodeposition and related coating processes, and was recipient of the AESF Scientific Achievement Award in 1995. He is a recent past president of the Institute of Metal Finishing.