EDUCTOR AGITATION FOR A NICKEL ELECTROPLATING INSTALLATION

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The design, installation and optimization of an Eductor agitation system for a 6000l (approx. 1300galls) nickel tank is described and its performance measured against the formerly used air agitation system. A total of 20 eductors were installed, 5 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 7-10x were measured giving 36% deposition rate improvement and shorter process times (71% improvement). Reduction in nickel thickness variability (ie. edge build-up) of up to 92% was measured. Metal/acid fume was virtually reduced to zero emission.

INTRODUCTION

Since the earliest days of electroplating in the 1840s, agitation has been recognised 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, eg. oxidation of solution constituents, loss of solution conductivity, 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, in use several other additional features are now recognised as possibly more important characteristics:

- no oxidation of solution constituents by an agitating gas
- no loss of solution conductivity
- no fume except from gas evolution at 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 that 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 using jigs and explores:

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

DESIGN OF EDUCTOR SYSTEM

General specification.

The existing tank was 1.8 x 1.8 x 1.8m with working capacity of 6000l or 1345 gallons. A temporary pumped ring mains was to be submerged around the bottom perimeter leaving the air *sparge* tubes in place. Filtration would be kept as a separate pumped circuit. Agitation at 40 turnovers per hour was specified, which meant an agitation flow rate of 1345 x 40 /60 = 897 galls per min, of which 20% is pumped and 80% venture induced. Thus the total pumped volume is 179 Gpm for which rate a 2.2kW (three phase, 415V) pump was required.

Eductor numbers

The total eductor input was shown above to be 179 Gpm. Using 3/8in eductors at 35 ft total dynamic head, charts indicate a nozzle flow of 9.2 Gpm which leads to a requirement of 179÷9.2 = 19.45 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 were supplied by Serfilco UK under the trade name *serductors*.

System costing

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

2.2kW Pump and 20 3/8 in. eductors	£ 1652
PVC pipework (1.5 and 2in.), bushes, elbows, tees, valves	466
Electrical connections, re-wiring of heaters etc	391
Total	2509

Additional down-time, emptying of tank and rinsing were not separately costed. However, it should be noted that failure to thoroughly clean the tank walls 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 leading to excess debris being produced. A future installation would 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 can be enhanced for clearer vision by bleading in air to the solution feed line which leads to a bubble plume. This is an important step because most plating solutions are too deep in colour for detailed observations to be made and the plume cannot be seen or photographed for record and analysis purposes.

OPERATION OF EDUCTOR AGITATION

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 9 x 5 x 3/8in of low carbon steel flat stock and were stamped for identification. Thicknesses of nickel would be measured by micrometer as the thickness range was typically 0.002-0.009in. giving a weight gain of ~20g over five hours 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 jig connection
- Vapour degrease in trichloroethylene
- Submerge in wax tank for masking
- Knife removal of wax for exposed area
- Etch in sulphuric acid for 5min. at 7.5V
- Nickel strike for 5min. at 5V
- Nickel electroplate for 5.5hrs. at 1.5V and 4A
- Rinse and vapour 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. From these measurements two parameters could be determined: the overall deposition rate (weight gained by the test panel), and the metal thickness distribution variance. These parameters could be similarly determined for the eductor agitation system.

Optimization of eductors.

The eductor flow circuit consisted of a square plan ring main containing 20 eductors, 5 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.

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

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 and 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, the glass vials developing colour changes. The accuracy is claimed to be +/- 10%, vials are stable if stored out of sunlight at 25˚C, and they are easy to operate and read.

A standard nickel sensitive tube was used (part no. 67-28-871, Nickel 0.25/A) having a measuring range of 0.25-1.0 mg m^{-3}. It utilizes the HCl-solubility of nickel and a dioxim indicator which turns pink.

RESULTS.

Deposition rates.
A deposition time of 5.5 hrs. 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 were as follows.

Air agitation	20.4 g weight gain	3.709 g/hr deposition rate
Eductor agitation (all 30˚)	24.9	4.527
Ditto (opposites 30 and 60˚)	27.8	5.054

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 0.008in variation in deposit thickness and using a standard positioning code the results are given in fig.2. Positions 1,5,11 and 15, representing the four corners of the test panel and positions 7,8,and 9 representing the central portion of the test panel. (On this graph the pink horizontal line represents the test piece thickness as baseline).

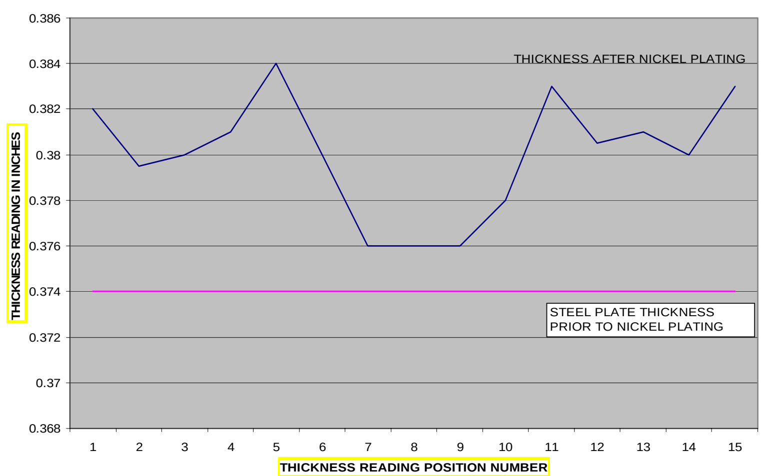

Fig.2. Thickness variation for air agitated nickel plating.

The procedure was repeated for the two eductor agitation formats, the graphs being given as figs.3-4. Using all eductors at 30˚ the variation was 0.006in and for the 30 and 60˚configurations the variation was 0.003in.

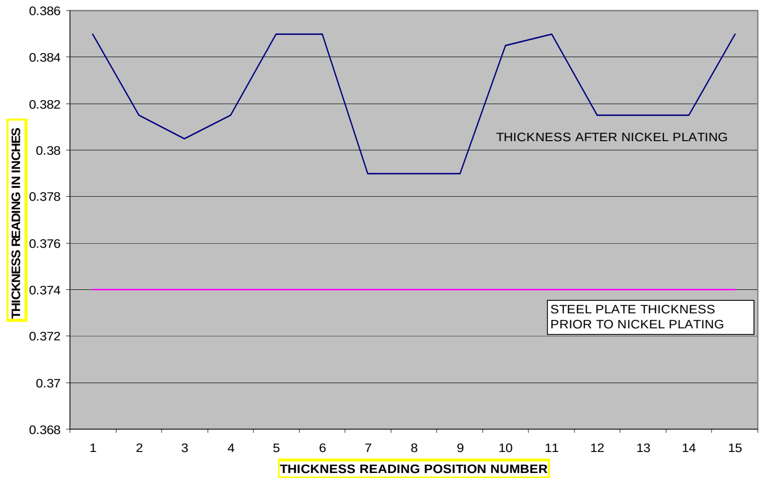

Fig.3. Thickness variation for eductors at 30˚

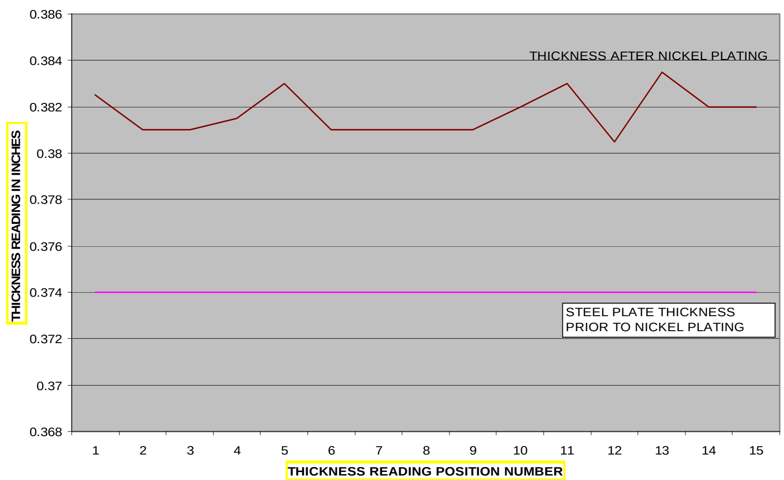

Fig.4. Thickness variation for eductors at 30 and 60˚

Clearly the thickness variation has been substantially reduced and a comparison of the air agitation with the optimized eductors is very marked.

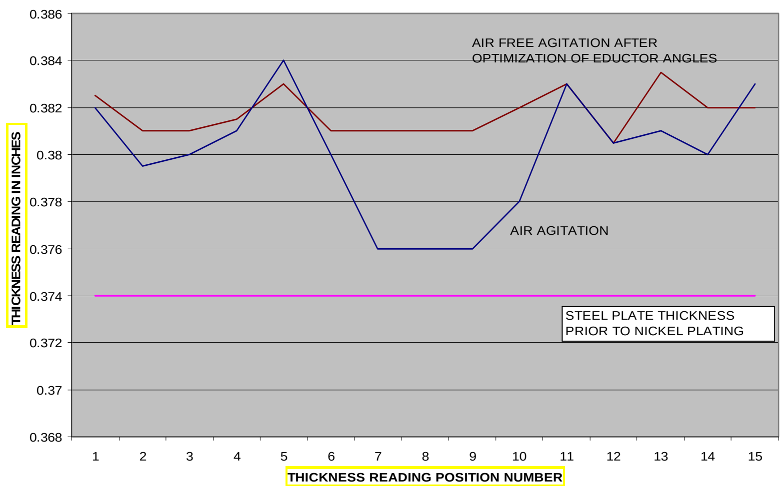

Fig.5. Comparison of thickness variations for air and optimal eductor agitation.

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

Airborne emissions.
Draeger tube measurements were made under each agitation regime. The results are as follows.

Air agitation	Airborne emissions of 0.5-1.0 mg Ni per m^3
Eductor agitation	0

The claim in the trade and published literature is for a reduction of over 90%. Clearly this is borne out in this investigation.

Observations of a qualitative nature undoubtedly indicated almost total elimination of noxious chemical fumes and there was little or no frothing and 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 giving extreme examples.

Criterion	Air agitation	Eductor agitation	Optimized eductor
Weight gain	20.4 g	24.9	27.8
Thickness variation.	0.008 in	0.006	0.003
Thickness at Corners	0.010 in	0.011	0.009
Thickness at Panel centre	0.002 in	0.005	0.007

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.

Agitation	Time to deposit 0.008in	Excess nickel at corners	reduction in time, %	improvement in waste, %
Air agitation	22 hrs	0.032in		
Eductors	8 hr 48 min	0.0096in	60	70
Optimal Eductors	6hr 17min	0.0023in	71	92

In terms of improved production the change over air agitation can be expressed in the following terms.

	Improvement in deposition rate, %	Improvement in waste (excess nickel), %
Eductor agitation	22	70
Optimal eductors	36.3	92

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 sirred 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 optimise the eductor plume flow,
- Empty tank and re-fill with plating solution,
- Circulate solution through filters and commence eductor electroplating.

Localisation of agitation may be avoided when the plumes are observed during commissioning. Thus work must be place sufficiently far away from the eductors to avoid high points of agitation where adjacent plumes overlap at impact on the workpieces. This is particularly important for say PCBs but less so for jigged 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.

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 jigged work and measured reduction in fume 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 ~1V 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 10-20%.
- 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 busbar-current and heater circuits, monitoring of filter cartridge accumulations etc. 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.

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