Comparison of local exhaust ventilation with other exposure controls used in electrolytic nickel plating

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Abstract. Workers in the surface treatment industry are potentially exposed to a range of carcinogens, asthmagens and skin sensitisers including nickel (Ni) compounds. Exposure occurs by inhalation, absorption through the skin, by ingestion or any combination of these three routes. Emissions from nickel electroplating tanks occur when the solution is agitated, which is essential to ensure the plating quality is acceptable. This is usually achieved by bubbling air through the plating solution. There are a range of measures that can be used to reduce airborne emissions from electroplating tanks. This paper describes a series of laboratory tests to evaluate the effect of different control measures on the emissions generated from an electrolytic nickel plating tank. The findings showed that LEV and eductors offer the biggest reductions in emission rate with both being similarly effective. Release of aerosol from the tank decreased as LEV flow rate increased. With the highest air agitation rate, and the LEV set to the manufacturer's recommended flow rate, emissions were reduced by more than 98% irrespective of the freeboard height.

1 Introduction

A survey carried out over the period 2008-2011 [1] estimated that there are approximately 3000 workers employed in around 450 companies in the surface treatment industry. These workers are potentially exposed to a range of carcinogens, asthmagens and skin sensitisers including nickel compounds. Exposure occurs by inhalation, absorption through the skin, by ingestion or any combination of these three routes. To ensure the plating quality is acceptable there needs to be a constant supply of nickel at the work surface. To achieve this, the plating solution is constantly agitated. This is commonly achieved by bubbling air through the plating solution. However, when the bubbles burst at the plating solution surface a fine aerosol is created, which contains nickel.

There are a range of measures that can be used to reduce or control the airborne aerosol emissions from electroplating tanks. These measures vary in efficacy, cost, complexity, and ease of use.

The aim of this laboratory study was to determine the effect on airborne emission rates of a range of electroplating exposure control measures [2]. To do this a small scale electrolytic manually operated nickel plating process was set up in the laboratory with the ability to evaluate the different control measures, including local exhaust ventilation (LEV).

2 Methods

2.1 Experimental set up

The plating facility, which was designed to mimic a manually operated small scale decorative nickel plating line used in industry, was housed inside a test room with internal dimensions 4 m x 4 m by 2.92 m high, located within a climate-controlled laboratory. The electrolytic nickel plating tank was 900 mm long by 600 mm wide by 900 mm high. The tank was operated at 55 °C by circulation of water through a titanium heating panel. The plating solution contained nickel sulphate, nickel chloride and boric acid as the main chemical constituents. It was circulated during the plating process, either by air or eductor agitation. Continued mixing of the plating solution is required so that a constant supply of fresh nickel ions is available at the workpiece surface, otherwise the plating process could stall resulting in poor quality plating of the article.

A sampling hood was positioned over the tank to collect the rising emissions during electroplating. This was designed according to ACGIH [3] guidance to ensure it received the rising thermal plume but did not actively generate an airflow at the tank surface. The effectiveness of the sampling hood was confirmed by both smoke and tracer gas testing.

The collected emissions were ducted outside of the room where sampling took place in the measuring duct before the air was filtered using high efficiency particle air (HEPA) H14 filters and discharged to the outside.

Isokinetic sampling was carried out in the measurement duct using inline sampling heads fitted

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with mixed cellulose ester filters with a 1.2 µm pore size. The filters were analysed for soluble nickel content using a method described in BS ISO 15202-2 [4]. Filters were extracted in deionised water at 37 °C and the nickel content in the extract was determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES). The limit of detection on each filter was around 0.2 µg soluble nickel.

Electroplating was carried out with 2 jigs, each with four test pieces (each 160 mm x 175 mm) on, giving a total surface area being plated of 0.448 m^2. The total plating time, i.e. time when current was applied, was 90 minutes.

2.2 Control measures investigated

The efficacy of different control measures was assessed by comparison of emission generation rates (µg Ni per second) from the tank. These were calculated from the nickel concentration determined in the measuring duct (amount of nickel on the filter, sampling time, sampling flow rate) and air flow rate through the sampling hood.

The control measures (exposure and process) investigated during this study were as follows.

2.2.1 Local exhaust ventilation.

The LEV opening was positioned along the rear lip of the plating tank and measured 900 mm wide by 80 mm high. The maximum LEV extraction rate investigated was 1260 $m^3.h^{-1}$. This was recommended by the electroplating tank manufacturer and is consistent with the upper design flow rate from ACGIH guidance. When not in use the LEV duct was blanked off.

2.2.2 Eductors

Eductors are an alternative to air agitation for mixing of the plating solution. It is a pumped circulation system which utilises the venturi effect. Tests were carried out using eductors as an alternative method for air agitation and were set up by the manufacturer. No alterations were made to the eductor set up throughout the eductor tests.

2.2.3 Freeboard height

This is defined as the distance between the top of the liquid surface and the top of the tank lip. The freeboard was maintained at 150 mm unless this was the parameter under review.

2.2.4 Air agitation

Air agitation is used extensively in industry to ensure the plating solution is well mixed. Air agitation was the default method of solution mixing for all tests, except where eductors were being tested.

2.2.5 Chroffles

These are small plastic balls that are placed on the liquid surface to reduce the effective open surface area of the plating solution.

2.2.6 Surface tension

The surface tension of the solution is controlled by surfactant concentration and was maintained at 49 (±1) dynes (determined for each test), unless this was the parameter under review.

2.3 Data handling

Statistical modelling was carried out on the air emission rate using Gaussian location-scale Generalized Additive Model (GAM) models. The purpose of such modelling was to confirm the conclusions drawn from the results of individual tests and also to look for interactions between control measures that might not otherwise have been apparent.

3 Results

3.1.1 Local exhaust ventilation

Operating the LEV at 100% of the manufacturer's recommendation (1260 $m^3.h^{-1}$) gave a reduction of emissions of greater than 99.7%. Figure 1 shows the effect of LEV flow rate operated between 0 and 50% of the manufacturer's recommendation. Data is shown for two freeboards (150 mm and 300 mm).

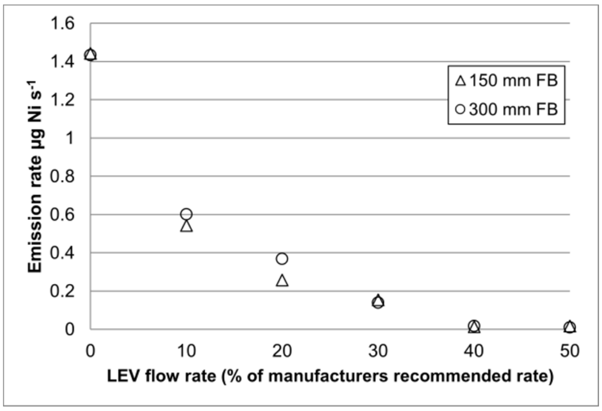

Fig. 1. Effect on emission rate as a function of LEV rate (expressed as a percentage of manufacturers recommended flow rate) with air agitation at 24 $l.min^{-1}$

3.1.2 Eductors

Tests with eductors were carried out with a freeboard of 150 mm at four different surface tension levels between 37 and 50 dynes. Compared to air agitation, eductors reduced the emission rate from the plating tank between 97 and 98.6% (n=15).

3.1.3 Freeboard and air agitation

Figure 2 shows the effect of freeboard and air agitation rate on the emission rate at differing freeboard heights. The surface tension for these data was 49 dynes.

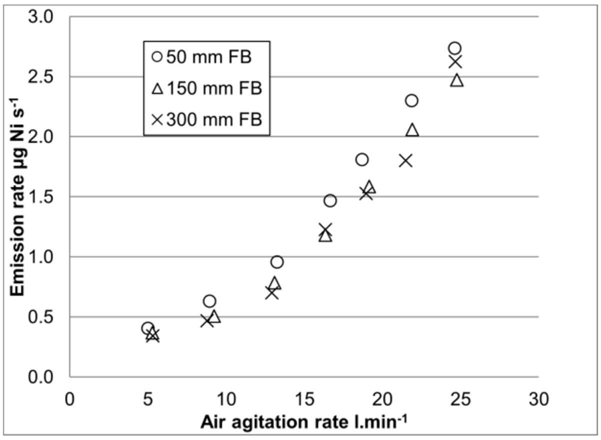

Fig 2. Effect of freeboard height and air agitation rate on emission rate (at 49 dynes)

3.1.4 Chroffles

Chroffles were added to the surface of the solution to reduce the effective open surface area. Tests were carried out at a range of air agitation rates between 5 to 24 l.min^{-1}. The effect of 100% coverage compared to no chroffles reduced the emission rate between 73 and 81%. Further tests at a range of percentage covering indicated there was a linear relationship between the emission rate and the percentage coverage.

3.1.5 Surface tension

The surface tension of the solution was adjusted to investigate the effect on emission rate. As the surfactant concentration was increased, the emission rate decreased. A maximum reduction in emission rate (53.5%), was achieved at 37 dynes compared to the manufacturer's upper specification (44.5 dynes). However, this was outside the manufacturer's specification. At 42.5 dynes, the lowest surface tension that was within specification, the reduction compared to the upper surface tension limit gave a reduction in the emission rate of 7%.

4 Discussion

4.1 Effect of LEV on the emission rate

All of the control measures, except LEV, reduce the emission rate from the tank by reducing the production of nickel aerosol. With LEV applied the production of nickel mist was unaltered, rather the LEV removes it at source, resulting in a lower nickel concentration emitted from the tank and therefore collected by the sampling hood.

Operating the LEV at 1260 m^3.h^{-1} (the manufacturer's recommended flow rate) the emissions were reduced by greater than 99.7%. The exact reduction at the recommended flow rate could not be calculated as the result from which the emission rate was determined was less than the analytical limit of detection. Reducing the flow rate to 50% of that recommended still reduced emissions by 99.7%. This suggests that the flow rate recommendations are over specified, although they are in line with ACGIH recommended flow rates which are also referenced in BS EN 17059:2018 [5]. However, it should be remembered that lip extraction applied to plating tanks are classed as capture hoods and therefore their efficacy is susceptible to workroom draughts and general air turbulence. In a real workplace the background air disturbances are likely to be higher than in the laboratory test room, and higher extraction rates may be required to ensure effective capture.

Tests carried out at flow rates between 10 and 50% of the manufacturer's recommendations (Figure 1) showed that the effect is not linear and that significant emission rate reductions (>70%) were achieved with the LEV running at 20% of the recommended flow.

Statistical analysis showed that emission rate decreases as LEV flow rate increases and reductions in emission rate of more than 98% occurred when using a high air agitation rate and running LEV at the manufacturer's recommended flow rate.

4.2 Effect of the other control measures

Air agitation had a significant effect on the emission rate, as can be seen from Figure 2. However, to ensure acceptable plating quality, the minimum air agitation rate was considered to be approximately 16 l.min^{-1}. At this level, typically emission rates were half that obtained at 24 l.min^{-1}.

The effect of freeboard heights had minimal effect on emission rates, see Figure 2. The statistical analysis of the data showed emission rate reductions of 12% (at 150 mm freeboard) and 18% (at 300 mm freeboard) when compared to that obtained at 50 mm freeboard.

With chroffles covering the whole surface of the plating solution, the emission rate was significantly reduced. However, the quoted coverage in the results section (Section 3) is notional as the total coverage cannot be achieved given the spherical shape of the chroffle. The actual tank surface area covered with a 100% coverage was calculated to be 78.5%. Whilst the use of chroffles reduced emissions significantly, there are practical considerations to consider and they are likely to be impractical for short term plating times, typical of decorative plating. They may also increase the dermal exposure risk as they usually have to be handled. In addition, there is anecdotal reports of chroffles becoming trapped between pipework and also being transferred into rinse tanks following the plating process.

It is understood that the primary purpose of the surfactant is to ensure good solution mixing, rather than as a means of controlling emissions. Altering the surface tension between the manufacturer's upper and lower specification resulted in a relatively small reduction in the emission rate.

Emission rate reductions of between 97 and 99% were achieved with the use of eductors. The statistical modelling verified these findings, with the emission rate fitted values calculated by the model showing reductions of more than 98% across a range of surface tension measurements. The results show that whilst eductors do not entirely eliminate emissions, a significant reduction occurred with the use of eductors which appears to be independent of plating solution surface tension. The main mode by which eductors reduce emissions is by eliminating the need to bubble air constantly through a warm solution. As the bubbles burst through the surface of the solution, they generate an aerosol creating an inhalation risk.

4.3 Hierarchy of control considerations

It should be considered that all controls studied, except for LEV, work by actually reducing the amount of nickel aerosol generated and so would be considered to be preferable exposure controls in terms of their efficacy. LEV does not reduce the nickel emissions but achieves control by removing the contaminant before it can pose an exposure risk. Should the efficacy of the LEV reduce, or the system fail then control will be lost, and exposure will occur, i.e. it fails to danger. BS EN 17059 specifies "*appropriate protective measures shall be taken in case of failure or insufficient forced ventilation so that hazards for persons present are indicated*", and such measures could include "*interruption of electrolytic operations by shutdown of rectifiers*". This standard applies to new equipment and does not apply retrospectively to existing equipment. It should be noted that many of nickel plating lines with LEV will have been designed prior to introduction of BS EN 17059.

When considering the hierarchy of control [6], it is generally accepted that process driven exposure controls are far more likely to remain effective. Eductors are the means by which the plating tank solution is mixed and since this is a requirement for the plating process to work satisfactorily, eductors could be considered a "fail safe" exposure control because plating work would be halted if the eductors failed. Businesses can be expected to be more motivated to maintain critical process controls than standalone exposure controls. Therefore, whilst LEV and eductors are equally effective, eductors are considered the best control of those studied as they are effective and less prone to failure.

5 Conclusion

An evaluation of different exposure controls for electrolytic nickel plating has been carried out. The efficacy of these controls is now better understood, supported by robust quantitative scientific evidence.

Different exposure control scenarios for electrolytic nickel plating were tested and the potential effects on emissions have been evaluated. The findings for the emission rate data were verified by use of statistical modelling.

Eductors and LEV offer the biggest reductions in emission rate (close to 100% reduction) with both being similarly effective. LEV captures the nickel aerosol and removes it to prevent worker exposure, which means there could be a loss of control should the LEV system deteriorate or fail.

As the eductors are required by the process to achieve adequate mixing, robust emission control is more likely to be achieved on a consistent and sustained basis because they virtually eliminate the nickel aerosol emitted from the plating tank. This is preferable when considering the hierarchy of control.

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