Benchmarking water use in printed circuit board (PCB) manufacturing

Envirowise first produced a Guide for benchmarking water consumption in UK PCB manufacturing during 2001. Since then there have been significant changes in an industry that has become both smaller and more efficient in the face of competition from Far East-based producers. These pressures have encouraged companies manufacturing PCBs in the UK to embrace best practice and to reduce costs wherever possible. One area where savings can often be made is in the use of water.

This Benchmarking Guide provides data and advice that could help you to:

- Reduce your water consumption by up to 50%
- Improve your profits by reducing water and effluent costs
- Compare your water consumption with that of other PCB fabricators
- Implement no-cost and low-cost measures to reduce your water consumption
The survey

In order to enable individual PCB manufacturers to compare their water consumption with figures from the rest of the UK PCB industry, a broad survey of water use by UK PCB manufacturers was carried out by Envirowise in September 2005. Responses were obtained from a wide-ranging cross-section of manufacturers, representing much of the UK’s PCB manufacturing capability from the smallest to the largest companies. The annual production range of respondents was from 350 to 168,000 m²/year of finished board.

This Benchmarking Guide:

- summarises the survey findings, allowing you to compare your water consumption with that of other UK PCB manufacturers;
- explains how to calculate your site’s specific water consumption;
- helps you to estimate the cost savings you could achieve by implementing best practice;
- presents an action plan and suggestions for reducing your water use and thus increasing your profits.

This Benchmarking Guide provides an update of an earlier guide published in 2001 and reflects changes that have taken place in both the size and scale of the UK PCB manufacturing industry over the last five years. It includes additional details of newer technologies that have come into use in recent years and outlines how they can be implemented to minimise water consumption. This new guide, whilst enabling PCB fabricators to benchmark their relative water consumption against newly collected statistics from a broad cross-section of the industry, also recognises that absolute comparisons are rarely possible owing to the disparate technologies that are individually employed.

Impact of manufacturing process and equipment

The results of the water survey provide industry data that can be used to give a general benchmarking indication of how your company’s water consumption compares with that of other UK PCB fabricators. However, it is not possible to make absolute comparisons, because of the wide variety of circuit board types produced and the range of different processes and equipment used by the industry. Some companies employ direct plate processes rather than electroless copper, while others favour horizontal equipment over vertical process lines. It is also important to note that not all companies actually carry out all stages of the manufacturing process themselves, with some preferring to subcontract out certain operations such as solderable finish deposition.

Therefore, when making decisions regarding water consumption it is important to understand how specific processes and types of equipment can influence the overall water use efficiency of a plant. For example, direct plate processes, particularly when used in horizontal conveyorised equipment, may reduce water demand by as much as 90% when compared with traditional metallisation routes. Another good example relates to solderable finishes, where there has been a proliferation of new processes in recent years to augment the traditional Hot Air Solder Levelled (HASL) finish. These new finishes all make use of multiple process stages and thus require water and rinsing. It has been found that the amount of water required can vary by a factor of seven times from the best to the worst performing processes. Finally, there are significant differences in water consumption between the inner and outer-layer processes used in circuit board fabrication, with the plated through hole processes using more water than the inner-layer processes. Consequently, it can be seen that direct comparisons with data from other manufacturers can only provide a broad indication of your company’s relative performance. More significantly, one of the best ways of reducing your company’s water consumption is to benchmark your performance after implementing the techniques outlined in this guide against your current performance.

SURVEY FACT

PCB manufacturers in the UK use over 2 million m³ of water each year, at a cost to the industry of more than £2.5 million.

SURVEY FACT

Specific water consumption does not depend on throughput.
Why reduce water consumption?

Large volumes of water are used in PCB manufacturing, mainly to rinse the boards between different processing stages. The rinses are used to clean the boards, terminate chemical reactions and prevent subsequent process baths becoming contaminated.

Water companies predict that water supply costs will continue to increase significantly and trade effluent charges are also rising steeply to meet higher wastewater treatment standards. Reducing the amount of water you use will also reduce the volume of water discharged as effluent - thus reducing both water supply and effluent costs. The survey found that water purchase costs ranged from 58 pence/m$^3$ to £1.24/m$^3$ and effluent discharge costs from 23 pence/m$^3$ to £1.22/m$^3$. There is thus a strong business case for improving your water efficiency, as water use in PCB manufacturing can be more than 3.5 m$^3$ per m$^2$ of board processed.

How the industry performs

Water consumption was found to vary considerably, with the least efficient sites using up to 100 times more water per unit area processed than the best (see Fig 1). The survey findings also show that specific water consumption, i.e. water use per surface area of board processed per year, tends to increase as the area of finished board per year decreases (see Fig 2). Sites processing fewer boards generally used more water per surface area of board processed compared to sites with higher throughputs. However, it should be noted that some of the smaller sites used water as efficiently as the larger sites.

Do you know how much water your company uses?

The best way to determine your water use is to compare meter readings over a period of, for example, four weeks. An alternative is to check your water and effluent bills. Water meters are usually fitted to the incoming supply, but may also be found at discharge points, on individual machines and after water treatment units. Water meter data allow you to:

- measure your water consumption accurately and thus manage water use better;
- identify water used by individual processes;
- detect leaks by highlighting discrepancies between water use calculated from the meter readings for incoming water and effluent discharge (after allowing for losses during processing).

Calculate your water consumption

The amount of water used during PCB manufacturing depends on a number of factors, including:

- the types of board manufactured;
- the number and types of production steps;
- the use of water management and re-use techniques;
- the specific process technology used and the type of equipment (e.g. vertical or horizontal).

To account for multiple processing and rinsing steps during the manufacture of boards with differing numbers of layers, it is best to calculate the average water consumption in m$^3$ per surface area of board processed in m$^2$ (i.e. the ‘wetted’ surface area). For multi-layer boards, the surface area of board processed is simply the area of finished board multiplied by the number of layers.

Many PCB manufacturers could reduce their water consumption by 50%. For a small to medium-sized facility, this could represent cost savings of over £30,000/year.
Use Table 1 to calculate how efficiently your site uses water. This will allow you to compare your specific water consumption with that of other companies - regardless of company size, layer count mix and variations in throughput. Use the example, right, to help you.

Comparing your figures with the values given in this Guide will tell you whether your company can improve its water management and thus save money.

Photocopy Table 1 and use it to repeat the calculation after you have implemented water saving measures. You can also apply the calculation to particular processes. This may help you to identify areas with the greatest potential for cost savings.

How much could you save by improving your site’s performance?

The survey revealed a wide variation in specific water consumption across the UK industry. The larger companies typically had relatively low water consumption per unit area of board produced but, with the smaller companies, there was a wide range of efficiencies. Some companies were more efficient than their larger counterparts while others were very much worse.

Although absolute comparisons are not possible, it is reasonable to assume that, for many companies, significant cost savings can be achieved by implementing best practices to improve performance to match those of the best performers in the industry.

Table 2 will help you to calculate the savings that you might be able to make and it shows the calculation for the example company above right. The table also enables you to compare your performance with one of the best performing companies in the UK. The company, Graphic plc of Crediton, Devon, provided data on its water consumption for this study and also participated in an Envirowise Case Study (CS570) PCB manufacturer flushes out benefits of water use minimisation, which details the measures it has put in place to achieve this high water use efficiency. Depending on the size of operation and current performance, you could save significantly more than in this example. Some ideas on how to implement measures to achieve these cost savings are provided on the following pages.

How to improve your performance

Savings can be achieved in various ways - many involving no-cost or low-cost measures. Significant cost

<table>
<thead>
<tr>
<th>Table 1 Calculating your site’s specific water consumption</th>
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<tbody>
<tr>
<td>Volume of water used in the last 12 months</td>
</tr>
<tr>
<td>Total area of finished board during this period</td>
</tr>
<tr>
<td>Average layer count per board</td>
</tr>
<tr>
<td>Water consumption per surface area of board processed, ie specific water consumption</td>
</tr>
</tbody>
</table>

* For single-layer boards, the formula is simply \( \frac{A}{2B} \).
savings and other benefits have already been achieved by companies that have implemented simple measures in the following key areas:

- reducing drag-out;
- reducing rinse water use;
- recirculating and re-using water.

The company with the lowest specific water consumption in the survey uses counter-current rinsing, flow controllers, rinse timers, low flow rinses and dual purpose rinsing. It does not use sophisticated recycling technology.

The survey results show that sites that use ion exchange to purify rinse water have lower specific water consumptions than those that do not. The two respondents with the highest specific water consumptions do not use ion exchange technology. However, both companies stated that they used counter-current rinsing together with some other water saving measures. In these cases, unnecessarily high flow rates in the rinse tanks - particularly during periods of non-production - are probably wasting water.

Common water saving measures are described below, together with practical hints and tips to help you to implement a water saving strategy in your company.

**Techniques to reduce drag-out**

Drag-out of process solutions and subsequent contamination of rinse waters are the main reasons for high water use and wastewater generation at most PCB manufacturers. The volume of process solution dragged out when the board is removed from the process bath depends on the solution's viscosity, surface tension and temperature. As the temperature increases, the solution's viscosity and surface tension fall and the drag-out volume is reduced. Reducing drag-out means that less water is needed to maintain clean rinses, thus reducing water and effluent costs. There are a number of ways of reducing drag-out.

- **Consider drag-out/rinsing requirements when specifying new process chemistry.** Increasing the concentration of a process solution generally increases its viscosity. The result is a larger drag-out volume and a higher concentration of chemicals in

### Table 2 Calculating your potential cost savings/year

<table>
<thead>
<tr>
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<th>For your site</th>
<th>For the example company opposite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your specific water consumption (from Table 1)</td>
<td>A ( \ldots ) ( {\text{m}}^3/\text{m}^2 )</td>
<td>0.71 ( {\text{m}}^3/\text{m}^2 )</td>
</tr>
<tr>
<td>The best specific water consumption</td>
<td>0.18 ( {\text{m}}^3/\text{m}^2 )</td>
<td>0.18 ( {\text{m}}^3/\text{m}^2 )</td>
</tr>
<tr>
<td>How much your specific water consumption could improve</td>
<td>B = A – 0.18 ( \ldots ) ( {\text{m}}^3/\text{m}^2 )</td>
<td>0.53 ( {\text{m}}^3/\text{m}^2 )</td>
</tr>
<tr>
<td>Potential improvement</td>
<td>C = B/A ( \ldots )</td>
<td>0.75</td>
</tr>
<tr>
<td>Your water and effluent costs for last year</td>
<td>D ( £ \ldots )</td>
<td>£22,000</td>
</tr>
<tr>
<td>Your potential cost savings/year</td>
<td>( \ldots \times ) D ( £ \ldots )</td>
<td>£16,500</td>
</tr>
</tbody>
</table>
both increase the volume of rinse water required. Avoid the problem by asking your chemical supplier to review the solution concentrations needed in your process baths.

- **Allow longer drip times over process tanks.** On a manual line, fit a bar over the process bath for the operator to hook the board on. Programme automatic machines to increase the dwell time above the process bath. However, do not let the drag-out dry on the board as this can cause passivation and may prevent complete rinsing.

- **Withdraw racks slowly.** Ensure your operating practices result in a smooth and gradual withdrawal of the board. The speed with which the board is withdrawn from the process bath has a major influence on drag-out volume. The faster the board is pulled out of the bath, the more drag-out there will be.

- **Agitate boards to assist drainage.** Mechanical agitation can be incorporated into new process lines at the design stage.

- **Angle boards to assist drainage.** Altering the position of the boards as they are withdrawn from the process bath can also reduce drag-out. Boards withdrawn at an angle to the solution surface drain much faster than those drawn out perpendicular to the solution surface.

- **Use air-knives to remove drag-out.** Use an air-knife to direct a curtain of air against the board as it leaves the process tank, thus causing the drag-out to be blown off. Use of humidified air stops the drag-out drying on the boards. Air-knives are commonly found at the end of conveyors, where low-pressure air is used to blow or dam excess fluid away from the surface of horizontal boards.

- **Use softer bubble EPDM (ethylene propylene diene monomer) rollers.** It has recently been found that by simply replacing standard EPDM rollers with softer bubble EPDM rollers, a 40% reduction in drag-out could be achieved. Additionally, by using spring-loaded bubble EPDM rollers a further increase in drag-out reduction to between 50 and 60% was possible. These results were achieved on a flood module on a conveyorised process line.

### Techniques to reduce rinse water use

Techniques to improve the efficiency of rinse water use can be grouped under three main headings:

- optimising rinse tank design;
- improving the control of rinse water use;
- using alternative rinsing configurations.

The key issue when considering how to reduce the use of water for rinsing is the effectiveness of rinsing required. Simply reducing the flow rate without taking rinsing effectiveness into account may lead to loss of product quality or contamination of the next processing tank. It is, therefore, important to consult your chemical supplier to ensure adequate rinsing effectiveness is maintained.

**Optimising rinse tank design**

The main aim is to achieve fast and effective removal of drag-out from the board. This reduces the time needed for rinsing and minimises the concentration of contaminants on the board as it leaves the rinse tank. When specifying new rinse tanks, optimise rinsing performance by:

- selecting the minimum size of rinse tank in which the parts can be rinsed;
- locating the water inlet and discharge points at opposite ends of the tank to avoid short-circuiting of the water flow;
- using a flow distributor/educter to feed the rinse water evenly;
- using mechanical mixing or other method of creating turbulence.

**Improving the control of rinse water use**

- **Install a flow controller** in the rinse tank’s water inlet pipe to optimise the volume of rinse water in the tank. Flow controllers are washers that flex as the water pressure increases, thus reducing the diameter of the pipe. The controller thus maintains a relatively constant flow of water into the tank under variable water pressures.

- **Use a conductivity control** to monitor the concentration of metal ions in the rinse tank and control the amount of dilution water added. As the concentration of metal ions increases, the conductivity of the rinse water rises. When a threshold level is reached, a solenoid valve opens to add the required amount of dilution water. Traditionally, conductivity is measured using a conductivity cell with electrode

### SURVEY FACT

**Over 85% of respondents have reduced drag-out by the simple, but effective, measure of increasing drip times.**
pairs. This is not ideal in situations where the electrodes become contaminated and covered in particles, as they can give false readings. A newer type of conductivity probe works on magnetic principles that do not require the high maintenance of contact electrode technology to give more accurate conductivity measurements.

**Fit a timer control** to control the amount of dilution water added to the rinse tank. Timer controls operate by opening the water inlet valve for a preset length of time. They are operated either by pressing a switch or by using a photocell to detect the presence of a board. Timer controls are a lower cost alternative to conductivity controls.

**Using alternative rinsing configurations**

- **Install counter-current rinsing** with two or more rinse tanks in sequence. In this technique, clean water flows into the rinse tank farthest from the process tank and overflows, in turn, into the rinse tanks closer to the process tank. The first rinse becomes contaminated with drag-out and, with time, reaches a stable concentration below that of the process solution. The second rinse stabilises at an even lower concentration and uses less rinse water than if there is only one rinse tank. The more rinse tanks there are, the lower the rinse rate needed to remove the process solution adequately. Counter-current rinsing can reduce rinse water use significantly.

- **Use low-flow spray rinsing** with low-flow directional nozzles for drag-out rinses, single rinses or multiple rinses. This technique reduces rinse water consumption dramatically.

- **Carry out dual-purpose rinsing** to reduce the number of rinse tanks operating. This technique involves using the same running rinse or spray rinse for rinsing boards from more than one process tank. Use only when the quality of rinsing is less critical.

**Recirculation and re-use**

Consider all opportunities to recirculate and re-use water for various duties around the site.

- **Install a closed-loop system to recirculate cooling water.** In its simplest form, this means pumping the cooling water to a storage tank for re-use and using a feed-and-bleed system to top up the tank with fresh water. If necessary, install an in-line chiller unit to cool the recirculated water.

- **Filter and re-use water from brushing/surface preparation.** Once any particulates have been removed by the filtration system, the water can be re-used. A horizontal-band filtration unit is usually combined with a feed-and-bleed system for topping up with fresh water.

- **Use ion exchange to purify rinse water for re-use.** An ion exchange system containing both cation and anion resins is a cost-effective way of purifying the rinse water for re-use in the process.
Action plan for water savings

- Establish management responsibility for action to reduce water use and wastewater generation.
- Monitor how much water enters your site and how much wastewater is discharged. If necessary, install meters.
- Measure water use and wastewater generation for each process area and produce a map of water use across your site.
- Calculate your site’s specific water consumption.
- Estimate your potential cost savings from implementing best practice - use Table 2 to help quantify the possible savings.
- Use your potential cost savings to win support from senior management for a programme to reduce water use and wastewater generation.
- Review opportunities to reduce water consumption by:
  - reducing drag-out;
  - reducing rinse water use;
  - recirculating and re-using water.
- Set realistic targets for improvements across the whole site and for each process.
- Implement cost-effective water saving measures for your site.
- Continue to monitor water use and report cost savings.
- Review progress and, if necessary, revise your targets.

Remember: If you don’t measure it, you can’t manage it.