NEW APPROACHES HELP REDUCE THE COST OF INERT SOLDERING

Process Adjustments and New On-Site Systems
Address Consumption and Unit Cost

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Use of nitrogen for inert soldering in the assembly of PCBs continues to increase worldwide in both wave and reflow soldering operations. More and more, assemblers are recognizing the value of inert soldering in improving joint quality and yield while reducing sensitivity to process fluctuations ('process window widening'). This is especially valuable in fine-pitch, BGAs and integrated components assembly, double-sided assemblies and bare copper printed circuit boards (PCBs) [1].

Although often perceived as a pure added cost, nitrogen soldering generally proves to be cost-effective because of increased yield and quality improvements. On a per-board basis, the cost of inert gas is low compared to the value of the board itself. Even so, cost control is important. This article reviews techniques and solutions that can reduce the cost of inert soldering while optimizing the benefits it brings to the assembly process. There are two basic approaches to cost reduction: optimizing or reducing unit consumption and reducing unit cost.

Begin by Determining the Right Atmosphere Purity

Many companies find themselves in a quandary regarding the quality of atmosphere required for their particular process. This is complicated further by the fact that few published papers seem to agree as to the optimum ROL [Residual Oxygen Level]. Additionally, there is a question whether the same atmospheric quality is required throughout the length of the soldering tunnel. The decision to use an inert process has been made to achieve specific benefits. If the appropriate atmosphere quality is not achieved, these benefits may be lost. On the other hand, injecting more nitrogen than necessary adds costs. How, then, do we find the optimum balance?

There is no single answer. The optimum atmosphere is generally user specific. Expressed in PPM (parts per million), it can be 50 PPM for one user and 500 PPM for another. Factors include the particular paste used (formula specific), the type of board finish, and the smallest pitch present on the assembly. If the primary motivation for inerting the soldering process is aesthetic or residue levels, it could be cost-effective to set a much higher oxygen level -- as high as 10,000 PPM -- if at that level the desired residue level is obtained [2].

While experimentation can determine the optimum atmosphere for a specific application, it is time-consuming and it can be expensive. Instead, users often opt for a somewhat subjective PPM level, which is often unnecessarily low and costly. There are, however some guidelines based on research, which can facilitate optimization of the atmosphere. To begin with, let us list some of the expected benefits of inerting [3]:

- ROLs < 10,000 PPM reduce discoloration of substrate
- ROLs < 500 PPM improve flux residue removal
- ROLs < 200 PPM reduce solder ball formation
- ROLs < 100 PPM improve solderability with N-C/LR paste

Although there are a number of other reasons one may choose to inert the soldering operation [e.g. use of OSP or multiple soldering processes, defect reduction, more reliable solder joint, etc.] The above list should suffice for our discussion.

There are two situations where nitrogen inerting is applied: reflow soldering and wave soldering. These must be examined separately.

Wave Soldering

Inerting the wave soldering system may be done in a number of different ways. Systems are available that protect only the solder pot area, either with a blanket of nitrogen gas bled over the wave crest or via a hood design. The latter may also be retrofitted. Actual ROLs are hard to establish in these systems. Consequently, the atmosphere and inert gas flow levels are often set based on the manufacturer's suggestion. Optimizing or reducing the nitrogen consumption is usually a maintenance and set-up issue. Provided the inerting device is installed properly and well maintained, a common experimental objective is to find the right balance between flow and dross production.

Tunnel designs of different length and designs are also being offered. In the case of tunnel systems, the atmosphere content varies and is specific to a process. Where spray fluxing and Low Solids Fluxes are being used, using nitrogen to drive the spray fluxer and inerting this area may be a good idea. This can prevent alcohol from self-igniting at a certain concentration. In the pre-heating area, the temperature of the PCB is raised from ambient to about 100°C -- where the bottom of the board may actually reach 145 - 150°C. This graduation will be reflected in the ROL. Whereas the beginning of the pre-heating zone (the board is still 'cool') does not need the lowest ROLs, at the end, adequate protection from oxidation (flux and metals) is required. The most stringent requirements must be met in the soldering zone proper. Here we demand the lowest ROLs of the process. Translating this into values, always keeping an eye on the above list, we could state:

- Fluxer area < 1000 PPM ROL
- Pre-heater entrance < 500 PPM ROL
- Pre-heater exit < 150 PPM ROL
- Wave area < 50 or even < 20 PPM ROL

Experiments, experience and the literature seem to indicate that it is unnecessary to go below these values.

Reflow Soldering:

The reflow process can be described best as a measured heating process. The equipment does not provide flux or solder. These are incorporated in the paste and cover the pads on the PCB and parts of the metallizations on the component. Hence, the function of nitrogen is quite different from that in wave soldering applications. In reflow, the goal is increased surface tension due to the lack of oxides in the surface of the solder. Also, the fact that flux does not have to perform the function of protecting metal surfaces against the oxygen of the air leaves more activity in the paste for the wetting process during reflow. Hence the convincing argument that by inerting with nitrogen, we may ‘open the process window’ and use Low Residue and Low Solids Fluxes.

Atmospheric purity is largely dictated by the thermal profile established for the particular assembly. Although equipment advertises extremely low ROLs in the peak zone, these are rarely required to furnish all the benefits of a good nitrogen process. The board begins at ambient temperature at the entrance zone, usually 'plateaus' at 160 - 170°C prior to the peak zone and reaches 220 - 225°C at its maximum. Based on this data, we would consider the following values ‘safe’ for most applications:

Entrance zone < 500 PPM; Plateau area < 150 PPM; Peak zone < 100 PPM

However, in many cases even slightly higher values may be employed successfully - some researchers now claim that these values are more stringent than actually required. Experience indicates however problems with the oven atmosphere stability at these higher PPM that is why a safer set point may be desired. Others claim occasionally that the above PPM values are too high, despite experimental and process data. More experimentation is called for in this area. Recognizing that incremental nitrogen required to reduce PPM follows a logarithmic curve; significant nitrogen may be saved by establishing the maximum PPM level that will produce the desired soldering results.

Reducing Unit Consumption: Conserving N_2

After introducing their own nitrogen-capable soldering equipment, most equipment manufacturers have spent considerable efforts in redesigning for nitrogen effectiveness. As a result, various innovations now allow a very reasonable nitrogen consumption rate that still varies widely from vendor to vendor. Therefore, it may be important to consider Nitrogen consumption as key decision criteria for new equipment purchasing. Vendors claim with their respective assumptions should be studied carefully in order to make the appropriate comparisons. A higher capital investment to achieve better inerting is common. However, cost-of-ownership equipment modeling may indicate lower operating costs and better long-term payoff.

Because of the nature of the equipment-selling business, little attention has been drawn to existing higher-volume nitrogen-operated equipment. Fortunately, some users (advised by their equipment vendors) and other industry suppliers have recognized the need to improve the atmosphere performance of this equipment. The following review of the new innovations and user ‘discoveries’ can offer insights on nitrogen savings.

O_2 monitoring:

Of the existing nitrogen-capable equipment, only a small percentage features a built-in analyzer. Because the cost of an oxygen analyzer can be relatively high ($5,000 - $10,000), this option may not have been purchased. The first question, then, is how can you control the nitrogen usage if you do not measure its efficiency? Years of experience have taught us that monitoring is a very effective step in controlling nitrogen usage.

A common discovery is that operators seem to increase the flow over time for various and unjustified reasons. If you have cautiously determined the optimum PPM for your process, monitoring may ensure that this level is maintained. Monitoring acts as a safety device that alerts you automatically of any changes or disturbances. Some 'retrofit' analyzer systems may provide other significant production benefits. For example, high PPM level alarms are readily available. If the atmosphere deteriorates to a defined set point, the operator is immediately notified. Other capabilities include PPM data logging - very useful in QC and ISO programs.

If the purchase of an O_2 analyzer cannot be justified, one option is to buy a portable analyzer for a given number of machines. This would allow the user to verify the oxygen content on a regular basis and correct the flow if necessary.

If your equipment is already equipped with an analyzer, calibration and maintenance is important. Flows adjustments based on a de-calibrated analyzer can be costly. An atmosphere audit with a portable analyzer and calibration service can generally be performed by your atmosphere supplier.

***N_2* hardware:**

Nitrogen lines, valves, and other regulating devices should be verified for leaks and proper settings. The pressure indicators, regulator, and flowmeters on the soldering equipment should also be checked out. If the flow of nitrogen was set based on flow information from the equipment supplier, then particular attention should be paid to the flowmeters. These have a defined scale that must be corrected for the actual nitrogen conditions. Be cautious: all flowmeters do not have the same reference conditions. They may vary significantly based on the country of origin of the soldering equipment. The main correction factor is pressure. If the flowmeters are pressurized (pressure at the outlet of the flowmeters), then the injected volume is far greater according to the following equation:

$$V_{actual} = V_{standard} * ([P_{actual} + 14.7]/14.7)^{1/2}$$

Atmosphere balance:

Under ideal operating conditions, the oven should be under a slight positive pressure. Positive pressure is achieved when gas exits the oven in a uniform pattern such that air is prevented from reentering. A balance should exist between the amount of nitrogen injected, the amount of atmosphere extracted, and the amount of air drawn in.

The most obvious points of air infiltration are the machine entrance and exit. As basic as it seems, the smaller the apertures, the less air that can be drawn inside the tunnel. One of the easier practices to reduce the opening is to install new curtains trimmed to the smallest size possible. Curtain attachments can also be reviewed to provide better sealing. Other possibilities include the installation of automatic shutters or gates on some equipment. These gates are activated by an automatic sensor that opens to allow boards in and out of the equipment. Not surprisingly, the success of this system depends closely on the spacing between boards and the production load.

In order to limit entering air, it may be worth verifying the exhaust systems. Have each of the zone exhausts been optimized? If the fans extract a given excess volume of atmosphere, then the same excess volume of nitrogen is required to maintain an adequate PPM level. Also, all external sources of airflow should be identified, reviewed or redirected away from the equipment - these include air conditioning ducts, personal fans, open doors and windows. Significant nitrogen reduction and PPM improvement have been reported when adopting the above measures [4].

Stand-by or Idle Devices:

Devices are available which reduce or stop the gas flow when no card is coming to the oven. Electric valves allow the flow of nitrogen to be stopped or reduced to an acceptable PPM level. This system is useful for low load periods, pick-and-place system failure or line stoppages for set-up or maintenance. Once the system senses new cards, the flow is returned fully and the oven is returned to the pre-determined atmosphere quality. These devices are available from some equipment manufacturers as a retrofit or can be fabricated easily in-house. Typically, this option is ideal for lines with sporadic production or low volumes.

Closed-loop system:

Nitrogen closed-loop systems have been introduced to the market recently [5]. Closed-loop control relies on dynamic sampling of the atmosphere to inject only the amount of nitrogen required to sustain the required O_2 PPM level. 'Open loop' systems must utilize a sufficient amount of gas to handle the largest boards and highest throughput regardless of the actual operating conditions. In order to satisfy the worst-case condition, the greatest amount of gas must be consumed at all times.

With a closed-loop system, the gas supply is split into two streams. The first stream is used to supply a constant flow of gas required to inert the oven under the best conditions (smallest boards and lowest throughput). This minimal flow also allows the removal of flux vapors. The second stream is regulated by a variable mass flowmeter controlled by a closed loop PID controller. The flow in this stream varies in response to the current PPM count as measured by an O2 analyzer. Closed-loop systems also offer other features such as stand-by mode and data logging.

The application of these systems, however, can be difficult at some unstable PPM levels. Difficulties arise from the slow response and non-linear conditions associated with maintaining an inert atmosphere. Additional difficulties arise with lower purity atmospheres. Also, because the system is driven solely by an oxygen analyzer, the maintenance of its components is critical. The user must ensure that the analyzer is calibrated and that the sample port lines are cleaned from flux residues.

If these applications and maintenance concerns can be handled, and provided that there is a difference between the different production loads, closed-loop systems can reduce nitrogen demand. Process benefits can also be important. However, high-quality closed-loop systems may be expensive and reduce or outweigh the accrued benefits. A complete assessment is thus suggested prior to acquiring such equipment.

Reducing Unit Cost: Nitrogen On-site Supply

After determining the most practical O_2 PPM level and reducing nitrogen losses, the next step is to look at nitrogen supply alternatives. Reducing unit cost of nitrogen is more than just a matter of supplier pricing: mode of supply is the most critical variable.

Today, most nitrogen used for PCB assembly is liquid nitrogen manufactured at the supplier's plant and delivered to the customer. While bulk nitrogen is very flexible, it is not necessarily the most economical choice. One new option available for lowering the cost of inert soldering is the production of non-cryogenic nitrogen at the customer site. The ability to produce nitrogen at the point of use has many advantages. To begin with, it requires few or no deliveries, eliminating distribution costs for immediate savings.

There are three technologies currently being used to generate nitrogen on-site: membrane, PSA (pressure swing absorption), and liquid assist. The choice among systems based on both technical and economical considerations. Technical data such as flowrates and purity required are critical. Economics include hours of nitrogen usage per month and the local price and availability of liquid nitrogen. Overall savings are market-dependent but can reach 40%.

Membrane Systems and Pressure Swing Absorption (PSA) Systems:

Since both membrane and PSA systems can produce relatively the same quality of nitrogen (generally up to 1000 PPM), it makes sense to review them at the same time. Membrane systems produce nitrogen through the separation of air by a solution-diffusion mechanism in hollow fiber polymeric membranes. On the other hand, PSA systems accomplish the separation of nitrogen from air by the process of selective absorption. Due to recent improvements, both systems can now produce high purity nitrogen, although at a high cost to achieve very high purity. Additions such as hydrogen-deoxo are required, reducing the savings, complicating the installation and raising safety issues. Typically, these systems will be selected for purity requirements above 1000 PPM O_2 if savings can be demonstrated. Since most users require a high purity atmosphere (< 500 PPM), the application of these systems at PCB assembly plants has been extremely limited.

Liquid-assist systems:

Recent improvements and development in on-site nitrogen generation have led to the development of modular and compact high-purity systems. The cost reductions these systems bring without compromising nitrogen purity is dramatic. Typical cost savings over liquid nitrogen ranges from 20%-40%. The liquid-assist system also brings the advantages of reduced truck traffic and higher reliability.

These systems use a special cryogenic process assisted by a small amount of liquid nitrogen. Typically this amount is 1-3% of the total nitrogen flow rate requirement. This liquid nitrogen is supplied through an integrated storage tank that also ensures uninterrupted supply as a back-up measure. These systems feature load following and automatic start-and-stop capabilities. The result is a very consistent and reliable high quality product with a typical maximum content of 3 PPM O_2.

Over one hundred liquid assist systems have been installed worldwide including a dozen for PCB Assembly operations. The names liquid-assist, APSA, and mini-cryo are interchangeably used. Similar to a bulk nitrogen supply, liquid assist systems are generally installed, owned and maintained by an industrial gas supplier. Due to recent technological innovations, even smaller and more economic versions of these systems have been developed. Where the cost of liquid nitrogen is prohibitive, such as in Japan, liquid assist systems as small as 1850 scfh (50 m^3/h) have been installed. In North America and Western Europe, systems starting at 5000 scfh (135 m^3/h or an average of 3 production lines) now offer economic advantages over bulk supply.

This system provides both the flexibility of a bulk liquid nitrogen supply, due to the high purity nitrogen it provides, and the reduced nitrogen unit cost that many PCB assemblers are looking for. Recognizing that most assembly users require both reliability of supply and high purity atmosphere (< 500 PPM), liquid assist can be the most viable option to reduce the unit cost of nitrogen.

References

[1] A. Rahn; “Nitrogen for Flow and Reflow Soldering?”; Surface Mount Technology Association Newsletter, Aug./Sept. 1997.

[2] Thibault, Bell, Lemieux; “Reduction of Residue Using Various Atmospheres”; Proceedings of the Technical Session, NEPCON West 1998.

[3] N.R. Cox; “The Influence of Varying Input Gas Flow On The Performance of a Nitrogen/Convection Oven”; Proceedings of the Technical Sessions, Nepcon West 1995.

[4] Langston, Chance, Smith; “Conserving Nitrogen at Reflow”; Proceedings of the Technical Session, NEPCON West 1997.

[5] D. Heller; “Introducing Closed-Loop Nitrogen Control”; Circuit Assembly Magazine, November 1997, pages 42-46.

