Nitrogen Atmosphere: Who Needs It?

By Dr. Leora Lawton

Dispelling the folk myths about nitrogen inertion's advantages and disadvantages.

A question frequently raised in PCB assembly is whether the advantages in nitrogen environments for reflow or wave solder ovens outweigh the additional cost. Some manufacturing engineers argue that controlling one's processes makes nitrogen unnecessary, whereas other engineers require nitrogen in all assemblies. This article seeks to answer the question of nitrogen use by polling manufacturing engineers, suppliers and OEM (original equipment manufacturer) customers of contract manufacturers. Somewhere along the axis from "never" to "always" lies the answer for each company.

Nitrogen: The Forgiving Process

The reason for using nitrogen is obviously to reduce defects. To understand its use beyond that simplistic pronouncement, knowing the circumstances for optimizing nitrogen's potential for defect reduction is important. Nitrogen is forgiving, which suggests that it can buy a manufacturer a window of opportunity to hone the manufacturing process—a window that can be helpful, if not essential. In some cases, reductions in defects may be an ongoing concern given the board specifications. Nitrogen inerting can produce better solder joints because it reduces the risk of oxidization, which is likely to occur with:

- no-clean processes, with the risk of solder balls
- repeated cycling of substrates, which degrades the copper
- low-ball soldering for fine-pitch.

Because of the forgiving quality of nitrogen, a good candidate for nitrogen inertion is an assembly that has one or more of the following characteristics:

- fine-pitch
- chip on board (COB) or direct-chip attach (DCA)
- prototypes
- costly or impossible rework
- complex assemblies
- requirements for high product reliability.

The most impressive reductions in defects may be obtained not in reflow ovens, but in the wave soldering operation. Wave solder is a difficult process. The requirement of "lining up" for the even wave of solder increases the risk of solder balls and opens. Several PCB assembly engineers suggest that one should inert with forgiving nitrogen, and then finesse the wave.

No magic formula exists for making the decision to use nitrogen inertion, so creativity for manufacturing solutions should be encouraged. Some engineers prefer using nitrogen, if at all, in reflow only; others prefer in wave solder only; others use it in both applications. Conducting tests is essential for understanding the optimal manufacturing solution. For example, an independent test confirmed a suggestion about using wave solder, as reported by one engineering manager at a contract manufacturer: "We also found out [through our solder provider] that we get better wave dynamics on the nitrogen wave nozzles [knife]. We don't have to run nitrogen, just compressed air, and we get better results than from our non-nitrogen nozzle."

Note that in the above case the supplier became involved in the customer's manufacturing process. The complexity of the products would leave customer satisfaction up to chance without a supportive relationship. The maxim that a supplier is not simply a vendor, but a partner, holds in this area as well. Equipment suppliers often give training and consultation about the optimal use of their products.

Suppliers can bring a good deal of research and consulting experience to the table.[1] Nevertheless, getting independent confirmation is essential. Research produced by a company with a vested interest is subject to bias. Engineers seeking to better understand the role of nitrogen, or anything else, should investigate claims by scrutinizing the research methodology. Under what conditions were experiments

Conditions Optimized by Nitrogen	Conditions Not Requiring Nitrogen
Expensive components or assemblies	Low-complexity assemblies
Prototype	Mature assemblies
Low volume	High volume
Nonreworkable components such as COB	Rework easily accomplished
No clean	Aqueous
Wave solder	Reflow
New technologies, such as fine pitch (low-ball soldering)	Standard technologies and packages
Reliability a priority	Cost a priority

TABLE 1: Considerations for nitrogen vs. oxygen.

run? Is that setting applicable to another manufacturing facility? Results found in one manufacturing context with its own set of parameters may not mean much for another.

An Issue of Dollars and *Sense*

The only disadvantage to using nitrogen is cost, so the decision becomes an issue of dollars and *sense*. If cost is the priority, then avoiding nitrogen may be prudent, but, if manufacturing considerations of product reliability or fine pitch come into play, then using nitrogen makes sense.

Even when using nitrogen inertion, you can control cost through additional ways. One obvious way is to carefully consider the ratio of oxygen to nitrogen. In a paper presented at Surface Mount International (SMI) in September 1997,[2] the authors suggest that oxygen ppm (parts per million) of less than 1,000 obtains a better yield for reflow. With wave solder, the authors suggest that a range of 400 to 2,000 ppm reduces dross and opens. The experiences of manufacturing engineers may vary as much as the ranges suggested in the SMI paper. When asked to compare his experience with the ratios noted in the article, one engineer at a large contract manufacturer said, "On reflow we keep it under 500 ppm, and we are able to do that with reasonable flow rates. We're nowhere near that on wave solder."

Getting an optimal profile of oxygen ppm when inerting with nitrogen also depends on the features of the equipment. Appropriate statistical process control can be used to evaluate the results of soldering. One can identify the apex at which decreases in oxygen diminish returns, fit this data to a cost curve and use only as much nitrogen as is justified by the reductions in defects.

Controlling the flow rate can be tied in with another cost-reduction strategy: recycling gas. Edward Chang of BOC Gases (Murray Hill, NJ) explained: "For convection heating you need a certain gas velocity, so that's where recycling fits in. If it's 100% fan-forced, then you can only blow so many cubic feet per hour, but that's not enough to give you the linear velocity that you want for the heat transfer. So, basically, you suck some of the furnace nitrogen and that also lowers the consumption."

Estimating the cost of using nitrogen goes beyond simply calculating the cost of the gas. If the options are an aqueous process with air vs. a no-clean process with nitrogen, then money is saved on the aqueous materials if the no-clean option is chosen. Yet, with no-clean a need exists to purge the flux to prevent build up, so, then, the cost comparison is about preventive maintenance vs. downtime. The cost of rework from the higher rate of defects is another factor in the cost equation. If the board cannot be reworked, such as with COB components, then the cost of materials needs to be adjusted. A picture of the total cost involved can tip the scale toward nitrogen use.

A cost-benefit analysis of materials and labor is a dollars and *cents* calculation. *Sense* enters the equation when considering the end use of the product. If defects are not tolerable under any circumstance, then any reasonable effort to reduce defects is prudent manufacturing. A quality manager at an OEM serving the networking and satellite communications industries stated, "When we made the decision to use nitrogen in all of our assemblies, we weighed the benefit, and our concern was more in terms of reducing the defects than in cost. We didn't do a cost-benefit analysis. We said, 'Okay, what does it do in terms of defects?' The issue is not cost. It's reliability."

What about Solder?

Some solder paste suppliers offer paste formulated for use in nitrogen inertion. Is it necessary? Said BOC's Chang, "We think the atmosphere is very much related to the type of flux that is used. It's the flux solids that matter. Each flux manufacturer has its own formulation, but it's still up to the user to let the flux supplier know what kind of atmosphere they are using. They should do a test run and see what kind of result they get."

Some engineers interviewed for this article discounted the importance of solder, saying other factors, such as the substrate material, are more pivotal. One comment was: "Nitrogen should help any solder paste."

Another engineer stated: "They do claim that with nitrogen you get a better wetting on the surface, but I think the phenomenon is due to oxygen and oxidization. It's not so much the nitrogen environment, but the air environment, that matters more for flux choice."

Brian Deram of Kester Solder Company (Des Plaines, IL) explained that, because nitrogen reduces the risk of oxidization and the kind of flux used affects the risk of oxidization, labeling solder paste "not for use in air" rather than "formulated for nitrogen inertion" would be more correct.

Equipment Manufacturers Provide Flexibility

In some instances manufacturers may want to inert with nitrogen, and in other cases forced air would be perfectly adequate. Fortunately, manufacturers of soldering equipment give PCB assemblers the flexibility they need. Of the 10 companies listed in the "*Circuits Assembly* Soldering & Equipment Survey" (April 1998) for wave solder equipment, eight sold equipment that had nitrogen-inerting capability. Of the 34 models listed, only nine did not have that capability. For reflow ovens, 32 of the 47 models include nitrogen capability, with all but one of the 14 companies offering a model that could be used with nitrogen inerting. Having equipment that can do both nitrogen and oxygen allows the diligent engineer to exercise judgment on manufacturing processes for each assembly.

Customer Requirements

"Do customers specify nitrogen?" is a question a customer-oriented contract manufacturer might ask. The answer is "rarely." Of the seven OEM representatives contacted who subcontract assemblies, five said they leave the decision up to the contractor. The other two OEM representatives said their engineers work with the subcontractor's engineers but rarely dictate any processes as long as they are assured of quality and product reliability. A manager of manufacturing engineering at one contract manufacturer said that one customer was a stickler for nitrogen, but other customers have not gotten involved in the decision. This pattern is yet another exam-

ple of the trend of OEMs increasingly relying on their contract manufacturers to lead in manufacturing technology.

The Process That Won't Go Away

The debate over flux importance illustrates an important point about the perception of nitrogen's effectiveness. The range of opinion is probably due in part to perception lagging behind technology. When fine-pitch components were initially introduced, nitrogen environments facilitated removing enough flux from the solder paste. Later, suppliers improved their solder paste, so that it could leave residue with no ill effects or be boiled off completely so one could use air. Then, the fine-pitch got finer and the pads got smaller, requiring the solder powder size to be smaller. Again, with the ratio of surface area to mass increasing exponentially as one moved to finer and finer pitch, oxidization became a bigger issue, and manufacturers went back to nitrogen. Thus, as the process of innovation, adoption and amelioration evolves, nitrogen goes in and out of vogue, or at least is no longer absolutely necessary, though it may be highly desirable.

The existence of outdated advice allowed some folk myths about nitrogen to float about. As a consequence, one can hear completely opposite statements about nitrogen. The evidence collected for this article suggests that nitrogen inertion's forgiving quality makes it feasible to have high yield and reliability in complex or immature productions. But, when the manufacturing process is understood and stable and the risk of product failure is minimal, then nitrogen would be overkill. Deciding whether to use nitrogen inertion involves the following three steps, but it is not a simple exercise:

- Identify manufacturing requirements (Table 1) in which nitrogen is advantageous.
- Work with suppliers for their consultations and research.
- Conduct independent tests of manufacturing processes.

Electronics manufacturing is a dynamic process. Being open-minded to the potential benefits of nitrogen when appropriate is essential for maintaining a balance between the highest level of quality required at the lowest possible cost.

References

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