Introducing Closed-loop Nitrogen Control To Solder Reflow

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To achieve higher levels of consistency in PCB output, process engineers are able to maintain tighter controls and reduce process-related defects by using closed-loop process controls. At every stage of assembly, from screen printing through placement to reflow, closed-loop systems help control the variable factors that can have adverse effects on the process.

In general, a closed-loop system tracks a process and takes action automatically to correct any deviations beyond pre-set parameters. The tighter the tolerances of those parameters are, and the more effective the closed-loop system is in maintaining them, the easier it is to maintain the high degree of process control required to produce consistent, high-quality output.

Within each process step, equipment suppliers have responded to assemblers' needs by developing closed-loop controls for the internal mechanisms within their particular systems. In solder reflow, for example, there are two fundamentally different categories of process control. The first are the critical processes that are essential to maintaining the proper time at temperature. In a reflow oven these include the heat transfer rate of each zone and the conveyor speed.

If these variables are not monitored and adjusted constantly, they can drift with machine load and wear. It would be virtually impossible to obtain consistently good profiles and solder joints without closed-loop control of these variables.

A second category of reflow variables, which are either inherently stable or have less impact on process integrity than the critical variables, have traditionally run in open-loop modes and are only now being subjected to closed-loop control in order to enhance process control. The most recent closed-loop system to be introduced is an innovative method for reducing nitrogen consumption by maintaining a pre-set PPM level of oxygen within the reflow tunnel.

Nitrogen usage raises both process and cost issues for assemblers. On the process side, reflowing in an inert atmosphere has been shown to produce improved wetting angles, shinier solder joints and reduced defect rates. This is particularly true for applications such as fine-pitch and double-sided assemblies, as well as bare copper PCBs. In addition, advanced technologies such as flip chip, which uses ultra-low-residue fluxes with very low levels of activity, produce better results when processed in a nitrogen atmosphere.

The cost of using nitrogen, however, is a significant issue for assemblers striving to reduce operating costs. Depending on where a facility is located, the base cost of nitrogen ranges from a low of \$0.0018/cu. ft. (in Scandinavia) to a high of \$0.0350/cu. ft. (in Singapore). As shown in Figure 1, annual operating expenses for nitrogen usage can easily reach many thousands of dollars, even in areas where the base cost is relatively low. The objective, then, is to reduce the operating cost to an insignificant level, enabling all assemblers to realize the benefits of nitrogen reflow.

To meet assemblers' needs for cost reduction without sacrificing the process benefits of nitrogen, a number of conventional methods and reflow technology advances have been introduced in recent years. Each method and innovation makes its individual, incremental contribution to lowering nitrogen consumption; using them in combination can produce a significant reduction in the amount and cost of nitrogen required to produce consistent, high-quality reflow yields.

Previous Nitrogen Reduction Methods

The first of the conventional nitrogen reduction methods involved reducing the size of the openings at both ends of the oven, to minimize the amount of air intake that occurs at these locations. Within the oven, a certain velocity of nitrogen flow is required to maintain a low PPM level of oxygen. This relationship can be stated in a formula:

$$\mathbf{M_c = V_c \times A}$$

where $\mathbf{M_c}$ represents the critical mass flow, $\mathbf{V_c}$ represents the critical velocity and **A** represents the opening area. Therefore, decreasing the size of the opening reduces the mass flow required to maintain a given PPM level of oxygen.

A second method reduced the turbulence of the nitrogen so that it would exit the oven in a laminar, or smooth, flow — an engineering challenge, since forced convection is turbulent by nature. This was attempted either with internal baffles or airlocks, or with horizontal tunnels added to each end of the oven. While the tunnels did prove to be helpful in reducing nitrogen consumption, they also added to the length of the typical oven, creating potential problems in factories where floor space is an issue.

Using Closed-Loop Control To Reduce Nitrogen Consumption

The most recent advance in reducing nitrogen consumption introduces the concept of closed-loop control to this aspect of reflow technology. Traditionally, U.S. reflow oven manufacturers designed their nitrogen-capable systems to function optimally in the range of 25 to 100 PPM of oxygen. Nitrogen gas flows of 1000 to 1500 SCFH were typically high enough to prevent the PPM from exceeding desired levels when the oven was under heavy board load. Given these circumstances, closed-

For example, in a conventional forced convection oven, the oxygen content can vary from 100 PPM up to as much as 5000 PPM under heavy board load, due to the drag-in of air and changes in internal gas flow patterns that can occur as boards enter and exit the machine. In order to maintain a more consistent level, such as 2000 PPM ±100 PPM, closed-loop systems that control oxygen concentration within the reflow oven are now available.

A closed-loop nitrogen control system works by integrating continuous oxygen concentration measurement within the reflow zone with the flow of nitrogen into the machine (as shown in Figure 2). When the closed-loop reflow system is first turned on at the beginning of the day, the system automatically calls for maximum nitrogen flow, to purge the machine until the desired oxygen concentration is achieved. The system then automatically reduces the nitrogen flow to an economical idle level. Each time board load increases, the system responds by increasing gas flow to maintain the desired oxygen PPM range, then drops back automatically to the idle level as the board load decreases.

In applications where more than 1000 PPM oxygen concentrations are desired, air doping systems are used to mix in air, at a constant flow rate, with the nitrogen supply before it enters the reflow oven. The closed-loop system varies the flow of nitrogen to maintain the desired oxygen PPM within the oven.

The second factor supporting the use of closed-loop nitrogen control is the ability to run at low gas consumption rates with a high, yet stable, oxygen concentration. For boards that are six to eight inches wide, a typical forced convection reflow oven consumes 750 to 1500 SCFH to maintain 25 to 100 PPM. However, years of process experience have indicated that, for all but the weakest fluxes, operating at 100 to 500 PPM gives excellent reflow results at a far lower rate of nitrogen consumption. It is only with closed-loop control, however, that these higher levels can be maintained without widely fluctuating variations in the PPM, in response to changing board loads.

realized by establishing the maximum PPM level that will produce the desired soldering results for each board type.

Once this PPM level is established, the closed-loop control system may be set to maintain the minimal amount of nitrogen required for each application. On a fully programmable reflow oven, PPM readings may be tracked in real-time and displayed on the machine's computer monitor. Further, since the sensor maintains a log of all actions, this history may be incorporated into the reflow profile data and recalled for boards processed in different batches, ovens and even locations

Additionally, a "standby" mode supports further nitrogen conservation. If a board does not enter the oven for a specified time, which may be pre-set by the user, the system allows the PPM level to rise as high as 1500 or 2000, effectively stopping the flow of nitrogen into the oven. Any number of occurrences, such as the placement system going down or the line shutting down for maintenance or setup, can trigger the standby mode. As soon as a board enters the oven again, the system re-activates the nitrogen flow, restoring the desired PPM level automatically.

The PPM level, the interval at which it is monitored as well as the degree of deviation from the pre-set level, may all be specified by the user. A built-in alarm capability allows the system to alert operators to out-of-range conditions. The system is fully retrofittable to existing machines and can be controlled as a stand-alone unit or integrated into a Windows-compatible oven control system.

In the final analysis, the process benefits of closed-loop control for nitrogen consumption will prove to be as important to the user as the economic benefits, on two counts. First, the tighter tolerances that a closed-loop control system maintains lead to greater consistency of output. Second, because the system supports repeatable nitrogen usage patterns, it helps replicate reflow results in multiple manufacturing facilities. In the drive to six-sigma production and zero defect manufacturing, every process tool that contributes to more consistent and repeatable output also enhances productivity.