Development of High-Speed Pb-Free Reflow Ovens

by Etsuko Iwasaki * and Kousuke Nakao *

ABSTRACT Taiwanese manufacturers of personal computers have achieved rapid growth and are seeking to penetrate the mainland Chinese markets in order to obtain further expansion of their operations and profits. They were supplying the market with personal computers under its own brand, but is changing over to a business model that concentrates on OEM supply to computer firms in Japan, North America and Europe. In addition assembling personal computers, they are also actively engaged in the assembly of other devices such as mobile phones and LCD monitors, and have grown to be a major EMS.

In their search for profits, Taiwanese users are demanding reflow ovens that offer higher productivity and reduced running costs. Our Salamander line achieved a major share of the Taiwan market, and we have set to work to develop new products that will respond to customers' needs. We have taken as the new product concept a multi-zone structure that is conducive to higher productivity, and achieves a level of heating performance that is fully compatible with the Pb-free process that is due to be implemented soon. And despite the large size of the system, nitrogen consumption is held to a level comparable to that of small-scale systems.

This system, which we have christened the "continental system", came on the market in May, 2004, and as of October some 60 have been shipped.

1. INTRODUCTION

It is some time now since China has been called the manufacturing powerhouse of the world, and there is a strong trend in the electronics and other fields for Japanese and Taiwanese manufacturers to penetrate that market. Recently the Pb-free process has partly been implemented, and Taiwanese users have been particularly anxious to obtain reflow ovens that will achieve higher performance and higher productivity and be compatible with strictly Pb-free processes. To meet these needs we have set to work on developing the Salamander line of large, multi-zone reflow systems. The characteristics and functions that users want are as follows:

(1) Easy adaptability to Sn-Ag (tin-silver-based) Pb-free soldering;
(2) No effect on products due to re-adherence of flux, combined with easy maintenance, including flux cleaning;
(3) Reduction in running cost;
(4) Inexpensive products;
(5) Ability to achieve quick delivery.

In order to satisfy all of these requirements we have carried out a product development program using an all-new concept based on a fundamental re-evaluation of existing system designs. Photo 1 shows the appearance of the Salamander XNK-1245 continental system developed in this program.

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2. DEVELOPMENTAL CONCEPT

2.1 Characteristics

2.1.1 Heating Characteristics

The most basic aspect of reflow oven performance is heating capacity, and this can be estimated and measured with reference to the precision with which the target temperature profile is traced. In the process of making Pb-free mounting practicable, the basic conditions of the temperature profile have changed moment by moment from circumstances such as the problem of heat resistance of the components. Figure 1 shows the basic temperature profile conditions adopted in developing

Photo 1 Appearance of the XNK-1245 system.

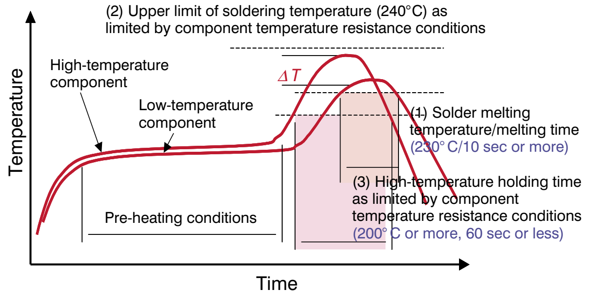


Figure 1 Basic temperature profile conditions for Pb-free surface mounting.

the reflow oven. If we adopt 240°C as the upper limit for soldering temperature from the heat resistance conditions of the electronic components, the temperature range ΔT permissible for Sn-Ag-Cu solder is 20°C. And if we further set the lower control value for the melting temperature of the solder at 230°C, the permissible value of ΔT is less than 10°C. In grappling with the problems of developing and improving reflow ovens, the target is to achieve a heating performance that clears this guideline for ΔT. Achieving a reduction in ΔT means improving the performance of the convection heating engine, as represented by the heat transfer coefficient α (W/m²K).

2.1.2 Cooling Characteristics

In Pb-free mounting, another important aspect to be controlled is the high-temperature holding time, which is limited by the conditions for heat resistance of the components. Thus strengthening cooling capacity as a means of controlling the cooling curve of the temperature profile is also an important topic.

2.2 Flux Collection

In order to prevent the adherence of flux to the structural members inside the oven or to the transport section, a collection mechanism must be provided, but in consideration of ease of maintenance, it is important to reduce cleaning frequency. The targets aimed at in this development project obviously included reduction in cleaning frequency, as well as improvements in ease of cleaning and flux collection capacity.

2.3 Reduced Cost

To respond to customers' pursuit of profit, reductions in equipment cost and running cost are important requirements. For this reason we aimed to transfer the facilities for manufacturing the new Pb-free reflow oven to Furukawa AVC Electronics (SUZHOU) in China in order to achieve even greater cost savings advantages than in the past. And for lower running costs, we also aimed at reductions in the amount of nitrogen used and in electric power consumption.

2.4 Quicker Delivery

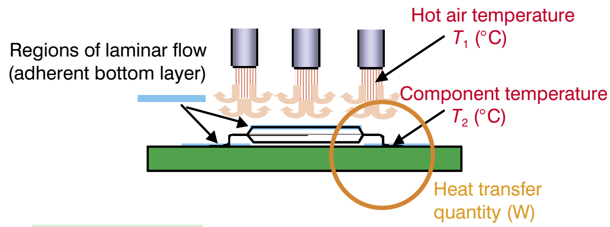
For an EMS, winning orders from customers requires immediate installation of mass-production facilities, and it is necessary to respond with much quicker delivery times than in the past. We therefore paid attention in system design to greater interchangeability of system components, and as far as possible to the elimination of the increased component count due to conveyer transport direction.

3. HEATING STRUCTURE

3.1 Fundamental Heating Concept

The heat transfer coefficient α, which is a basic characteristic related to the reduction of ΔT, may be represented by the equation in Figure 2 as a parameter that indicates the transient heat quantity per unit of time, unit of area and unit of temperature difference of the hot air stream that is discharged from the nozzles raising board temperature. The value of α is higher as the air speed and air volume become larger.

The results for heat transfer coefficient α will differ with the method and conditions of measurement. The heat transfer coefficient used here is the rise in temperature of a steel plate (S45C) measuring 250 × 250 × 2 mm.



$$Q_c = A \cdot \alpha (T_1 - T_2)$$

where: Q_c is quantity of heat supplied from convection heating engine to board
A is area of board/component that is heated
T_1 is hot air temperature
T_2 is component temperature/board temperature
α is heat transfer coefficient (W/m²·K)

Figure 2 Heat transfer coefficient α and equation for basic heating capacity.

Meanwhile the hot air stream above the board can also cause the displacement or shifting of components, so that the appropriate hot air conditions that can be used in component mounting are restricted to an extremely narrow range. In the "continental system", we have adopted a convection heating engine that upgrades the basic heating capacity to the greatest extent possible given these restrictive conditions.

The specific features of the convection engine are as follows:

(1) Removal of the heat resistant layer (adherent bottom layer) by the impinging of a perpendicular turbulent flow;
(2) Design of hot air nozzle configuration in such a way that no horizontal turbulent flow (dynamic pressure in the horizontal direction) is generated;
(3) Design of nozzle gangs and turbo engine so as to create a uniform hot air stream of high pressure and high-density;
(4) A flow-line simulation design for the hot air stream (free jet flow) that reduces the face-to-face tem-

perature interference between the top and bottom nozzles.

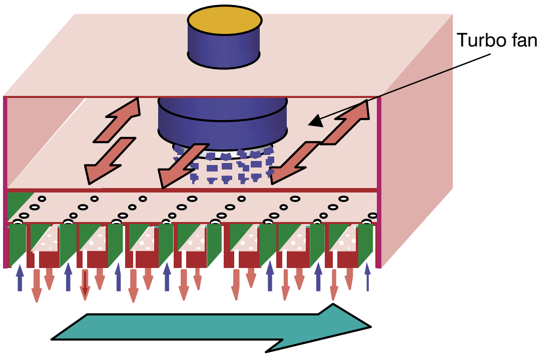


Figure 3 Convection heating engine.

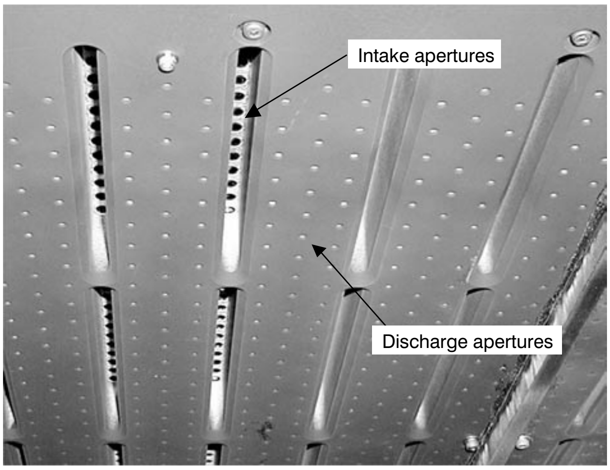


Photo 2 Appearance of nozzle panel for hot-air discharge.

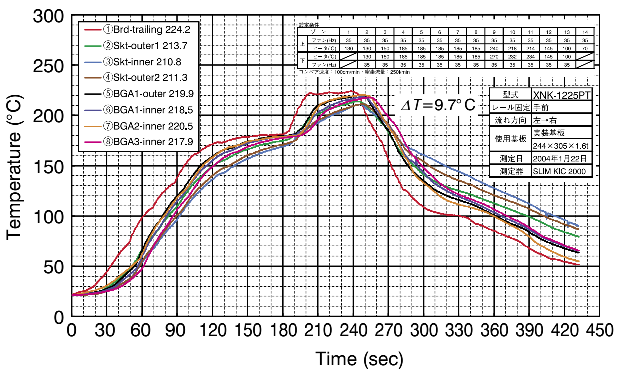


Figure 4 Typical temperature profile for test board.

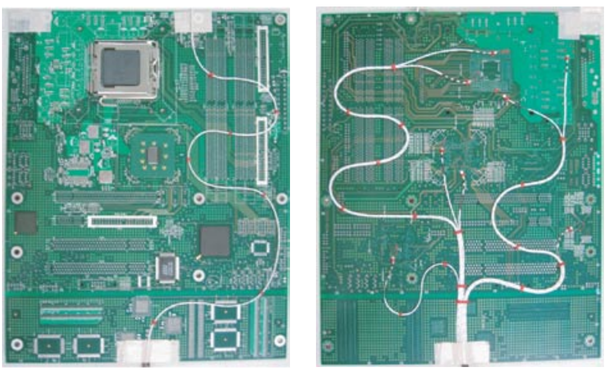


Photo 3 Test boards.

Figure 3 and Photo 2 show the convection heating engine that is installed in the "continental system". Figure 4 shows a typical temperature profile for the test board of this system, and Photo 3 shows the test boards used. Even for a highly complex test board, ΔT was less than 10 °C, making it suitable for Pb-free soldering.

The characteristic of this convection heating engine is that it adopts a method whereby immediately after the hot air stream that is discharged in the perpendicular direction impacts the board and becomes turbulent, the stream discharged from the vicinity is sucked in vertically and collected, so that no turbulence is permitted to arise in the horizontal direction. By balancing the various conditions of discharge and intake, it was possible to come up with a convection engine that combines low horizontal flow with low face-to-face temperature interference between the top and bottom nozzles.

3.2 Top/Bottom Differential Heating

The top/bottom differential heating method, which varies the quantity of heat supplied to the top and bottom sides of the board, produces the effect of suppressing a rise in component temperature while maintaining high temperatures at the soldered joints. In the past this method achieved its effect by supplying the top and bottom sides using different heat sources—hot air and far infrared heating from an IR panel heater.

In the "continental system" it was proposed to achieve this effect by means of a hot air heating oven, adopting a method of hot air discharge that reduces the face-to-face temperature interference between the top nozzles and the bottom nozzles. Figure 5 shows the principle of this approach to reducing temperature interference.

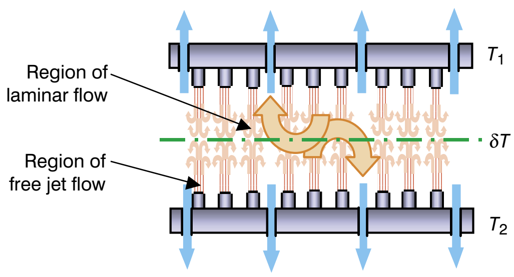
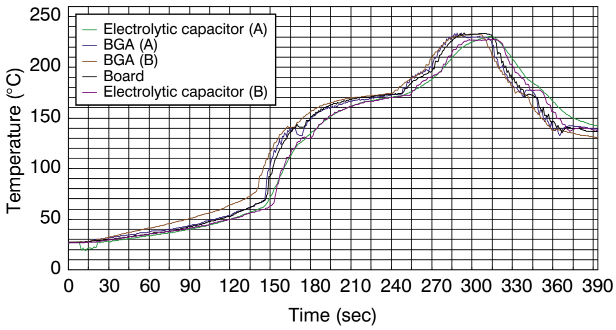


Figure 5 Principle of reducing temperature interference between top and bottom nozzles.

By making the free jet flows of hot air reaching the pass line laminar, and aspirating and collecting them from the vicinity in the perpendicular direction, it is possible to control the distance that the hot air reaches, making it possible to reduce top/bottom temperature interference. In the "continental system" it was possible, using this method, to have a difference in the temperature of hot air impinging on the top and bottom surfaces of the board of from 10 to 20°C. Figure 6 shows a typical case of mounting using top/bottom differential heating.

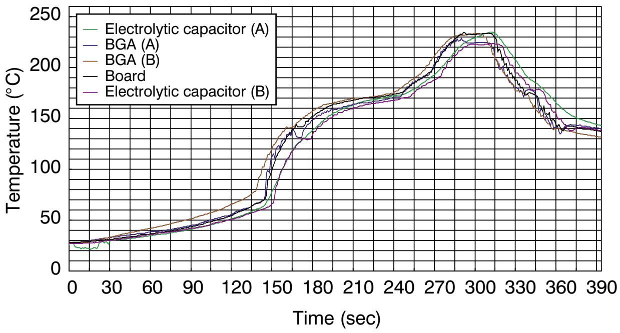
In Figure 6a we see an example of a temperature profile created assuming a conventional hot air oven, with the same hot air temperature setting for both top and bottom. Figure 6b, on the other hand, shows an example of



Zone	1	2	3	4	5	6	7	Cooling-1	Cooling-2
Top heater temp. (°C)	180	180	180	180	215	260	240	150	0
Bottom heater temp. (°C)	180	180	180	180	215	260	240	150	—

	Components temp.		Soldering temp.		ΔT
	Peak temp. (°C)	Holding time over 200°C (s)	Peak temp. (°C)	Holding time over 230°C (s)	
Electrolytic capacitor	228	53	230	0	3.5
BGA	234	53	233	23	

a) Same hot air temperature at top and bottom



Zone	1	2	3	4	5	6	7	Cooling-1	Cooling-2
Top heater temp. (°C)	175	175	175	175	205	250	230	150	0
Bottom heater temp. (°C)	185	185	185	185	230	275	255	150	—

	Components temp.		Soldering temp.		ΔT
	Peak temp. (°C)	Holding time over 200°C (s)	Peak temp. (°C)	Holding time over 230°C (s)	
Electrolytic capacitor	223	51	235	17	1.0
BGA	229	50	234	24	

b) Different hot air temperatures at top and bottom

Figure 6 Typical case of mounting using top/bottom differential heating.

top/bottom differential heating in which the shape of the temperature profile was adjusted to that in Figure 6a and the hot air temperatures for top and bottom differed by as much as 20°C.

The result was that under conditions of differential heating, in which the quantity of heat supplied from the top has been reduced relatively, the temperature of the bulk of the components mounted on the top surface of the board can be lowered by approximately 5°C, reducing the thermal stress on electronic components. And since at the same time it was possible to raise the soldering temperature, ample solder wetting time could be secured, with the result that an improvement in the quality of soldered joints was obtained.

The top/bottom differential heating method dramatically expands the range of products to which the Pb-free process can be applied.

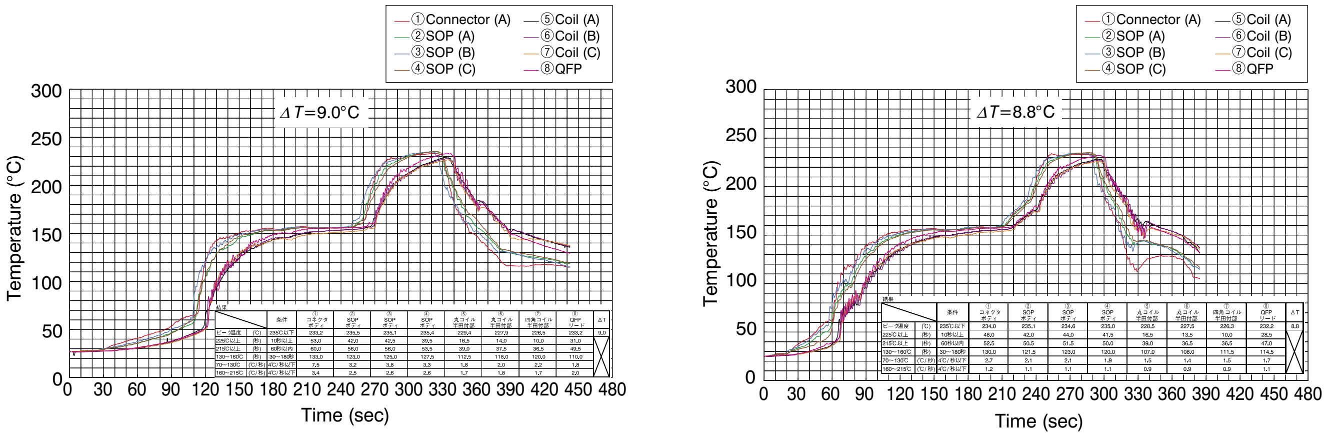
3.3 Number of Zones (Total Heating Length) and Heating Performance

With respect to system performance, in addition to improvements in the temperature characteristics, as typified by basic heating performance, there is a need for higher productivity. By means of the improvements in basic heating performance discussed up to the previous section, it became possible to effect drastic control of ΔT performance and component bulk temperature. To achieve higher soldering productivity, however there is a need, besides these rate-determining conditions, to secure pre-heating time and solder melting time. Accordingly in the “continental system”, the total heating length was extended by increasing the number of heating zones, thereby providing higher productivity. Figure 7 shows an example of raising productivity by increasing the number of zones. It was confirmed that even with a conveyer speed 25 % faster than that of the conventional system, it was possible to achieve a similar temperature profile. Figure 8 shows system layouts.

4. COOLING PERFORMANCE

In the conventional reflow oven the rate of decrease of temperature after passage through the high-temperature reflow zone has been taken as an indicator of cooling performance. More recently, however, in Pb-free mounting, it has been necessary to have temperature control across the falling-temperature process, for example, simultaneous control of both solder melting retention time (minimum value) and high-temperature dwell time (maximum value) of components with poor heat resistance.

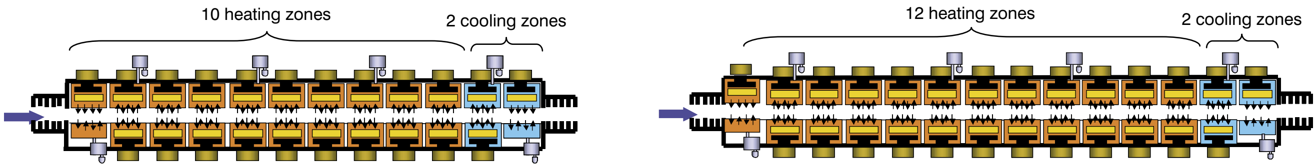
With a view to controlling profile shape in the intermediate processes of cooling, we have adopted for the XNK 1245 “continental system” a stage-wise cooling method of two-zone structure, in which a cooling zone of intermediate temperature, subject to temperature control, is incorporated into the early stage and a cooling zone in which the temperature of the atmosphere is kept low is incorporated into the later stage (Photo 4). Specifically the early stage uses the same convection engine as the heating zone, while the later stage uses an atmospheric cooling method, either air-cooled or water-cooled. Accordingly, for temperature profile standards requiring



a) Previous XNK-945 system with conveyer speed of 80 cm/min

b) XNK-1245 "continental system" with conveyer speed 100 cm/min

Figure 7 Raising productivity by increasing number of zones.

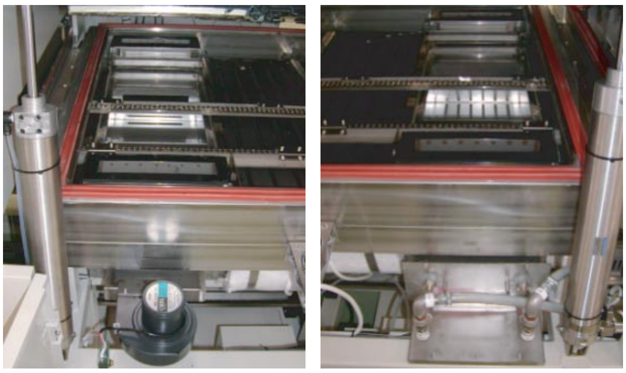


a) XNK-1045 system

b) XNK-1245 system

Figure 8 System layouts.

high-speed cooling, adoption of a water-cooled method is recommended. By means of this 2-stage cooling method, it has been possible to achieve, in addition to a high-temperature retention time control function, a steep cooling gradient and a flux-collecting function.



a) Air-cooled system **b) Water-cooled system**

Photo 4 Cooling system designs.

5. FLUX COLLECTION SYSTEM

Photo 5 shows the flux collection system. The fumes from the flux that are in the surrounding atmosphere are deposited in those parts of the oven where the temperature is low (below the condensation point). Since their adherence to structural members and the like can give rise to operational failure, cleaning must be carried out regularly. In the "continental system", the atmospheric fumes are condensed inside a cooled unit, and as the amount of condensate increases it accumulates in a collecting vessel. Collecting the flux in the vessel prevents re-vaporization in the air stream after condensation and liquefaction.

Photo 5 Flux collection system (center part).

6. CONTROL OF OXYGEN CONCENTRATION

Reducing nitrogen consumption is an extremely important aspect of controlling running costs. In the "continental system", an independent environment is achieved in each of the hot air zones, minimizing to the extent possi-

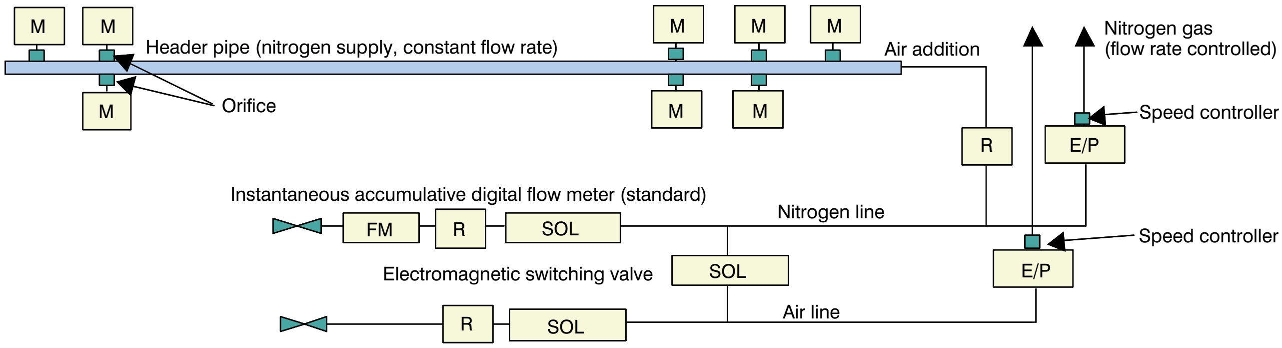


Figure 9 Nitrogen supply method.

ble any interference between zones due to the movement of hot air back and forth. Further by combining a gas curtain effect formed by the discharge and suction of the hot air with the inlet/outlet labyrinth structure that has been used in the past, we have achieved less oxygen concentration with the lowest level of nitrogen consumption in the industry. And achieving accurate flow distribution to each of the motors using the header pipes and orifices, we have controlled differences in oxygen concentration among zones. Figure 9 shows an overall view of the nitrogen supply method, and Figure 10 shows the relationship between oxygen concentration and amount of nitrogen supplied. Despite the method using a powerful hot air stream, only a little over 200 l/min of nitrogen supplied brings about an oxygen concentration in the oven of 100 ppm.

Figure 11 shows the stability of oxygen concentration under conditions of continuous board supply. Figure 11 shows ten glass-epoxy boards measuring 250 mm wide by 330 mm long by 1.6 mm thick fed continuously at a spacing of one board at a nitrogen supply rate of 200 l/m with oxygen concentration in the oven controlled to 300 ppm. It can be seen that even when the boards are fed continuously, there is virtually no change in the oxygen concentration in the oven.

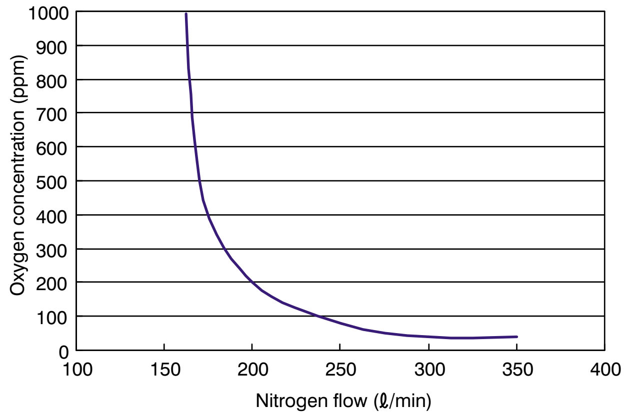


Figure 10 Relationship between oxygen concentration and amount of nitrogen supplied.

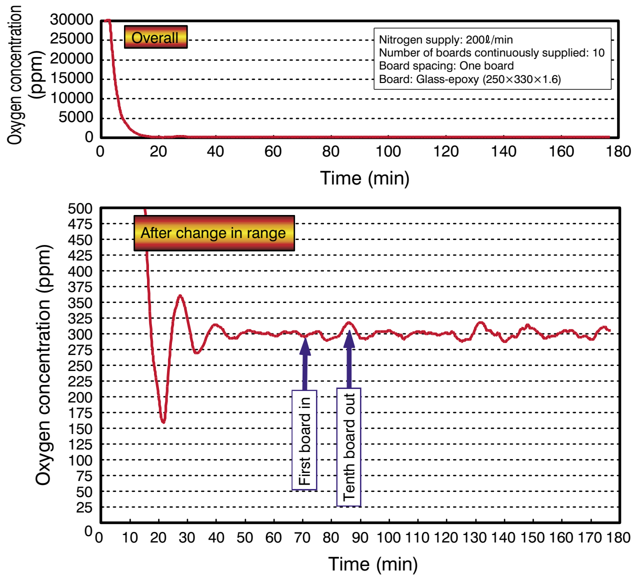


Figure 11 Stability of oxygen concentration under continuous supply.

7. SYSTEM DESIGNED FOR QUICKER DELIVERY, LOWER COST

To respond to the need for quick delivery, the system was arranged with a left-right symmetrical design, using a frame construction that is independent of the direction of transport. In systems in use until now, the time required from the customer specifying the direction of transport to the start-up of component fabrication was at least 1.5 months. The adoption of a right/left symmetrical design means systems can be semi-finished—from the frame, bottom heating unit, top heating unit and wiring, right up to addition of the transport system (conveyer). Thus when specifications are finally decided, all that needs to be done is to add the transport system and outer paneling, and carry out adjustments, allowing systems to be shipped in as little as three weeks. Figure 8 shows an overview.

To achieve lower costs the component count was drastically decreased, and screws were decreased and low-cost components used as a means to reduce the number of assembly processes. In particular the heating units use large numbers of identical components so that even a small saving in cost results in significant overall cost savings. At present quality assurance has progressed well domestically, and, with the start-up of manufacturing operations in the China plant, further cost reductions are anticipated. Table 1 shows the outline specifications of the XNK-1245 and XNK-1045 “continental systems” developed in this project.

Table 1 Outline specifications of Salamander continental systems.

		New Line-up	
		XNK-1245	XNK-1045
Overall dimensions	Length (mm)	6,300	5.680
	Width (mm)	1,300	
	Height (mm)	1,397	
Max. board width (mm)		460	
Number of zones	Heating	12 (11)	10 (9)
	Cooling	2 (3)	2 (3)
Length of heating zones (mm)		3,300~3,600	2,700~3,000
Power consumption (kVA)		66	56
Weight (kg)		2,700	2,500

8. STAND-ALONE NITROGEN SEPARATING SYSTEM

Salamander has been providing reflow systems with a built-in nitrogen separating system. There is a strong and on-going demand for nitrogen separating systems, particularly in those places that do not have the infrastructure for supplying nitrogen. In the systems used at present it has been possible to incorporate them within the reflow system but with the reduction in overall dimensions starting from the “continental systems”, internal space has become too limited to accommodate a built-in design. To respond to a strong need, a stand-alone nitrogen separating system that can be installed side-by-side is available as an option. Photo 6 shows its appearance. Its slim profile results in a compact unit that is visually pleasing.

In this nitrogen separating system, air at high pressure is passed through hollow membranes, taking advantage of the difference in its permeability to different gas molecules. Specifically nitrogen molecules penetrate more easily than those of oxygen, so that there are fewer nitrogen molecules at the membrane outlet and a gas of lower oxygen concentration is obtained. Under these same conditions, however, oxygen concentration inside the reflow system reaches a limit at about 1000 ppm, so for users who require lower oxygen concentrations in the range of 100 ppm, we supply a hydrogen generator system that adds hydrogen to the gas obtained by a nitrogen separating system to effect catalytic combustion of the residual oxygen. Hydrogen gas can be obtained by electrolyzing pure water and separating the oxygen and hydrogen. Table 2 shows the characteristics of the separating membrane, and Figure 12 is a schematic of the nitrogen separating system.

9. CONCLUSION

The Salamander XNK-1045 and 1245 “continental systems” developed in this project have achieved a high reputation from users in Taiwan and China from the standpoint of heating characteristics and nitrogen consumption. In terms of the problem of flux adherence and ease of maintenance, however, no final judgment can be rendered without field evaluations over the long term. We will address users complaints with a continuing program of plant visits, and by maintaining close business and technical relationships with them we intend to make improvements and introduce new products in a timely manner that anticipates users’ needs.

Photo 6 Stand-alone nitrogen separating system.

Table 2 Characteristics of separating membrane.

Pressure \ Flow rate	250ℓ/min	300ℓ/min	350ℓ/min	400ℓ/min
550 kPa	3540	5690	9230	Unmeasurable
600 kPa	2320	4060	6370	Unmeasurable
650 kPa	1740	3090	4720	7450
700 kPa	1140	2110	3570	5620
750 kPa	883	1670	2790	4350
800 kPa	667	1260	2240	3430

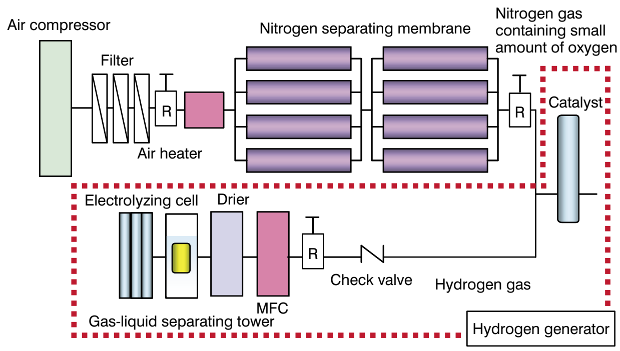


Figure 12 Schematic of nitrogen separating system.

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