

# Finding a Thermal Profiler to Match Your Application

By Philip C. Kazmierowicz, KIC

---

## Overview

*Thermal profiling and process monitoring equipment can tell you where your process is out of line and costing you money. These tips can help you decide what profiling tools you need to monitor your process.*

When someone says, "I'm gong to profile the oven," what he means is he plans to record the temperature at different points on a product as it travels through the oven. The reasons and methods for product profiling and thermal process monitoring are basically the same for all industries — whenever manufacturing requires a heat processing step, there must be some method to ensure that the product is heated or cooled to the right processing temperature.

There are many industries in which heat processing is a production step, and all use specific oven types. Some are conveyorized, some static, some batch and some elevator operated, but basically they do the same thing: The oven heats and cools a product to a specific thermal profile. If the actual thermal profile matches the specified profile closely enough, a product is produced that helps increase the company's profits. But, if the process moves outside the temperature processing parameters, the result is a defective product that reduces the company's bottom line.

## The Laws of Heat Transfer

The thermal profile of a product moving through a conveyorized process is a function of four factors:

- Initial product temperature.
- Temperature at the oven conveyor.
- Heat transfer rate at the oven conveyor.
- The amount of time a product spends on the oven conveyor.

As an example, consider a forced air solder reflow oven. The solder reflow process attaches surface mount electronic components to the top and/or bottom of a printed circuit board. It is a temperature-sensitive process: If the boards are heated up too

quickly, the components can crack, or the board may discolor and damage some of the smaller components. If the boards are heated too slowly, flux in the solder paste will be used up before the solder reflows, or the larger components may not completely solder to the board. Because the size and density of electronic assemblies vary, the reflow oven must be adjustable: The same temperatures and conveyor speeds that work for a 3 by 5" fax modem card will not work for a 9 by 12" motherboard.

A basic reflow oven might have a 3' load table, 15' tunnel and 3' unload table. Inside the tunnel, there usually are 10 heating zones and a cooling zone on top, and identical heating and cooling zones on the bottom; product is carried sequentially from one zone to the next on a conveyor. Each zone has a blower, heating element and control thermocouple. The blower forces air past the heating element, control thermocouple and on to the conveyor. The oven controller adjusts power to the heating element in each zone to keep the zone control thermocouple at the setpoint temperature. When all the control thermocouples are within, for example, 3° of the setpoint temperature, the oven is considered "in control" and ready to process product.

## Product Thermal Profiling

An oven is profiled by attaching three to 12 thermocouples to a sample product and recording the output of the thermocouples as the product travels through the process ([fig. 1](#)).

If the profile does not match specifications, oven zone temperature setpoints, conveyor speed and possibly blower speed are adjusted and the oven is profiled again. Because setting up the oven is an iterative process that can require many profiles, eating up precious production time, some product profiling systems include computer software that models the oven environment to allow the user to do "What if...?" analysis, or profile prediction. Such software can cut setup time by 50 to 80%.

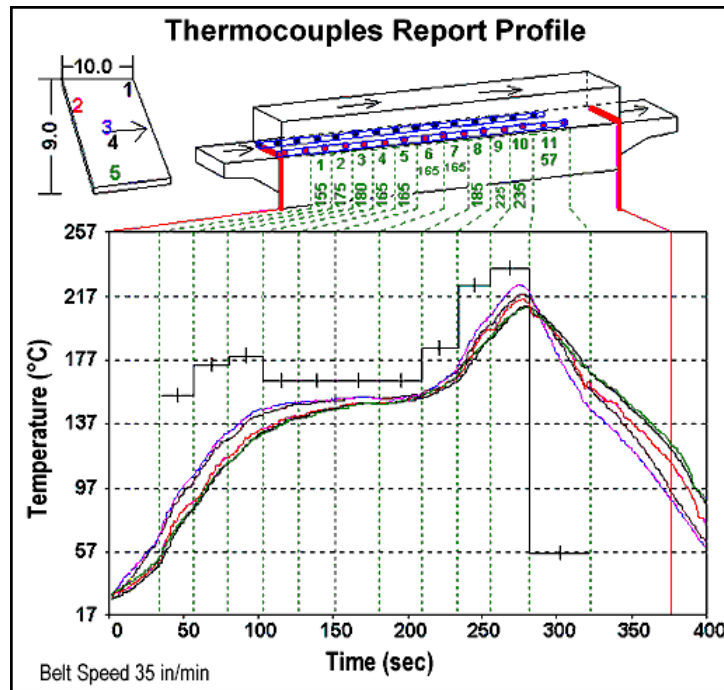
Once the correct zone setpoint temperatures and conveyor and blower speeds are set for a product, the information is stored as an oven recipe. Then, anytime that product is processed the recipe is loaded. Unfortunately, solder reflow ovens are not perfect, so a recipe that yielded the correct product thermal profile in the past may not yield the correct profile today. To minimize problems, many manufacturers profile each time they change the product being processed and once a day or shift just to monitor the process.

Performing thermal profiling to monitor the process contains three basic factors that affect costs. First, it takes time to have someone run the profile and evaluate the results. Second, if a problem is found, every product manufactured since the last profile was run becomes suspect. Third, if a processing problem occurs intermittently, it may be difficult to detect by running a profile, even if the oven is profiled as often as once a shift. The ideal situation is to monitor the thermal profile of every product so if the process starts to drift, adjustments can be made. However, this is not feasible given production constraints and product limitations.

## Thermal Process Monitoring

This method monitors significant process parameters for every product. If you understand the four laws of heat transfer discussed earlier, you understand that the only way to change the product thermal profile is to change one or more of its key process parameters.

In solder reflow, the initial product temperature is held adequately constant because the temperature inside the factory is fairly constant. As the product is processed, the temperature along the conveyor can be monitored continuously with an array of thermocouples mounted permanently at the conveyor level. Typically, there are two 0.25" dia. stainless



**Figure 1.** Each of the curved lines is the temperature as sensed by a thermocouple attached to a product as it passes through the oven.

steel tubes, with 15 thermocouples each, mounted on both sides of the conveyor just above the path of the product.

While no system has been established yet to monitor the heat transfer rate along the conveyor, most significant changes in this parameter are accompanied by a significant change in the temperature along the conveyor. The conveyor speed can be monitored with an optical sensor at the start and end of the tunnel. The sensor measures the time it

takes a product to traverse the length of the tunnel and calculates the conveyor speed.

Now that you understand the basics of thermal profiling, let's look at some profiling and process monitoring equipment. Thermal product profiling products have evolved to match the needs of users.

## Real-time Thermal Profiling

Real-time systems require a direct connection to a computer but offer the advantage of letting the operator see the temperature profile as the product moves through the oven. Viewing the data immediately can reduce wasted time (for example, you can stop profiling immediately if a thermocouple breaks) and can prevent overheating of the test product.

The strip-chart recorder was the first true profiler. Early models plotted one thermocouple attached to the product with a long wire trailing behind as it moved through the oven. Specially marked paper advanced through the strip-chart recorder at a preset speed, and a pen moved up and down depending on the thermocouple temperature. The profile appeared on the paper in real-time as the product passed through the oven. As with all older technology, these devices appear crude today, but in their time, they were the best way to see the product profile.

Technology next evolved to computerized trailing-wire profilers, which consist of a single trailing cable with inputs for up to six thermocouples (fig. 2). Instead of a paper printout, the profile is displayed in color on a PC. To profile, the trailing cable plugs into a circuit board that is connected to the PC. When the product exits the process, the thermocouples are unplugged from the cable and the cable is dragged back through the process. With trailing-wire profilers, profiling during production may not be easy because the trailing wire makes it difficult to place product on the conveyor behind the product being profiled.



**Figure 2.** Computerized trailing-wire profilers consist of a single trailing cable with inputs for up to six thermocouples. To profile, the trailing cable plugs into a circuit board that is connected to the PC.

## Datalogging Profiling Products

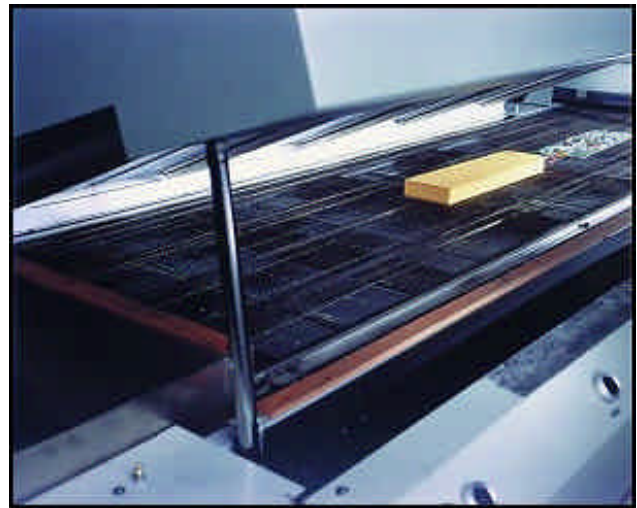
To eliminate the trailing wire and allow processes to be profiled during production, the datalogger profiler was invented. This device accepts three to 12 thermocouples and runs through the process behind the sample product, storing temperature profile information inside its internal memory. Once the datalogger emerges from the process, it is taken to a PC, plugged into an RS232 port and downloaded. The datalogger revolutionized the electronics assembly industry by allowing the product profile of any process to be quickly and easily verified.

While it eliminates the need for a PC on the shop floor, the datalogger offers one disadvantage: It does not show product temperature in real time. Also, because most solder reflow ovens do not have a product-viewing window, if the product or datalogger

falls off the conveyor or gets stuck in some way, both could be lost.

## Real-time Pass-Through Profilers

Basically a profiler with a radio transmitter, this profiler sends temperature data, as it is sensed, back to a remote receiver. The receiver attaches to the user's PC, where the profile data is shown in real-time on the monitor. Real-time pass-through product profilers combine the convenience and flexibility of the datalogger with the safety and immediate response of real-time trailing-wire profilers (fig. 3).



**Figure 3.** A wireless pass-through profiler has a radio transmitter that sends temperature data, as it is sensed, back to a remote receiver. It can be enclosed in a heat-protective shield, as shown here.

Each profiler model has its particular uses. Wireless dataloggers/transmitter profilers are convenient and can be moved easily from process to process for product profiling. However, some processes cannot accommodate a wireless pass-through profiler because of very high temperatures, long duration's within the tunnel, size of the actual tunnel opening or other reasons. In these cases, a trailing wire profiler must be used.

Some pass-through profilers combine real-time data transmission and datalogging capabilities and can be used in either mode or both modes simultaneously. These units are selected when the user has changing needs that require real-time and data downloading.

## Process Monitoring Systems

The two process parameters measured on a continuous basis are oven temperature along the conveyor and conveyor speed. Often, the temperature at the oven conveyor is monitored by

one or two heat-resistant tubes or other protective devices containing evenly spaced thermocouples that are permanently mounted close to the process conveyor. Custom fitted to each process tunnel or conveyor area, the tubes are connected to a data acquisition system that plugs into the user's PC or attaches to a circuit board that plugs into the PC. Every few seconds, the probes send temperature information to the PC, which displays the temperature readings of the zone-control thermocouples and the probe thermocouples at the conveyor level. By seeing real-time data, moving graphics and continually updated numerical statistics, the user can determine whether the temperature along the conveyor is in sync with readings from the control thermocouples.

The conveyor speed is measured with an optical sensor at each end of the oven. The sensors calculate the time each board spends inside the oven and can be used to record exactly when a board enters the oven or how many boards are in the oven at any given time. Some process monitoring systems provide a barcode reader to record the serial number of each board as it enters the oven. Current process data is saved and can be compared with defect data to determine how process variations relate to defects. Most process monitoring systems will work with a trailing-wire or pass-through product profiler to display the product profile on the same screen as the temperatures at the process conveyor ([fig. 4](#)).

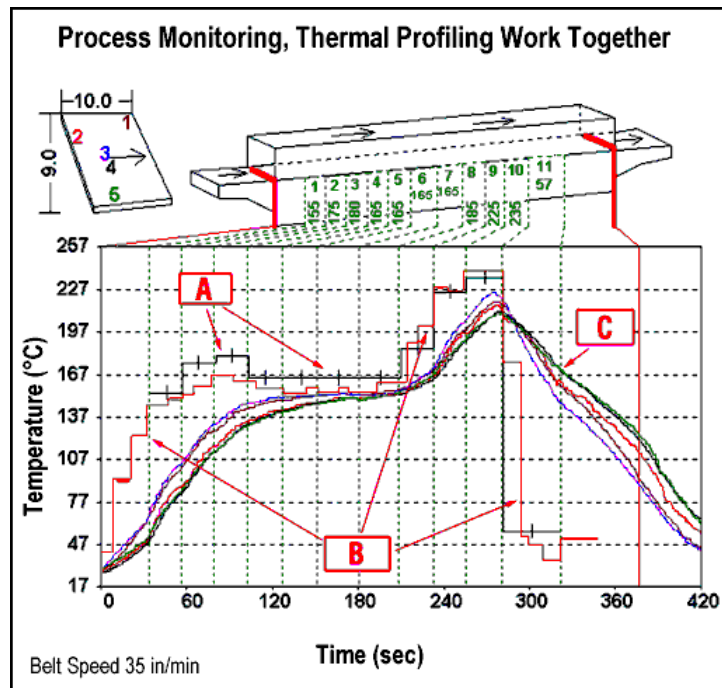
## Additional Products

All process monitoring systems and profilers have their own software programs, which is the key feature to consider when selecting a product to suit specific thermal control applications. Every profiling

equipment manufacturer has software programs for profile prediction, automatic file saving and screen tools for segmenting process/profile data into minute sections for extremely detailed analysis. Software is available that runs on the same computer as the process controller and/or is compatible for downloading to spreadsheet programs, and all can generate reports that can be printed on a range of printers. When deciding upon a profiling/monitoring product, be sure to watch a software demonstration and try it out before you make a purchasing decision.

Production software is the newest and most advanced software used with thermal monitoring systems. It

estimates what effects real-time changes in process parameters will have on the product thermal profile and continuously displays a simulated production profile based on how the current process parameters differ from the last time the oven was profiled. The user sets limits on all profile statistics, and should the process fluctuate during production and the product profile drop below or rise above any of the parameters, alarms activate. To the extent that all key process parameters are monitored, this system can literally stop you from processing bad product.



**Figure 4.** This sample process monitoring graph shows "A," the oven setpoint; "B," the actual thermal profile of the oven as sensed by the thermocouples of the thermal monitoring system; and "C," the map of the traveling product profile thermocouples.

The ideal thermal process monitoring and profiling system would be one that could "talk" to the process controller, find problems and make adjustments to the process automatically, bringing it back into the ideal profile parameters. This is what everyone wants, but it is not yet a reality. Both thermal process equipment manufacturers and thermal monitoring/profiling equipment manufacturers are working toward this goal.

## Tips to Point You in the Right Direction

When faced with a choice of product profiling, process monitoring, or both, ask the following questions about your application:

- Are the parts or products thermally sensitive in any way?
- How expensive are the assemblies, components or coatings of the product? How does the heat process affect them?
- Do you run a high volume of product in a single lot? Does this require shift changes during continuing production?
- Do you run short lots of high volume production, where each needs a different thermal process recipe?
- What is the typical rejection rate?
- How hard or easy is the product to rework? How much time is spent in rework?
- What is the dollar cost of rework? How does this detract from your product profit margin?
- Do you thermally process products that cannot be reworked?
- What is your average of field failure that is traceable to thermal process problems?
- Is your thermal processing equipment relatively old?

- Do you use a variety of different thermal processing equipment, each with different thermal stability situations?
- Do you require accurate thermal process tracking records for your product?
- Do you do a lot of thermal process "experimentation" when developing new products?
- Are you establishing or planning to establish your company as ISO 9000 certified?
- Is setting up your thermal process equipment, or correcting problems within your equipment, labor-intensive?

To determine what your process demands, total up the affirmative answers and separate them into two groups: anything to do with the product itself and anything to do with the process equipment. Some may cross over, but depending on what is most important to you, decide which column to put each item in.

If you can answer yes to only one or two questions, then either your process is so stable that you are not experiencing any

problems, or you already have a good thermal process control system in place. If the lists have more than four items and are about equal, you should look into both thermal process monitoring and profiling equipment. If everything seems to fall into the area of the product, then an accurate product profiler may help you.

Whenever possible, try to put a dollar cost to your answers. This will help you decide whether investing in thermal monitoring products really will benefit you in the area that is the most important—your profit. If you waste a lot of money (translate that into labor hours, burned components, reject product) due to thermal process problems, or if you can increase your profits (translate that into more quality product in a shorter time with less labor) by streamlining your thermal process production area, then you should really take a serious look into what products and technologies are available to help you address these areas.