Thermal process optimization provides reduced energy consumption

Due to the higher melting point of lead-free Sn-Ag-Cu alloy, higher reflow soldering temperatures are required for lead-free PCB assembly. Consequently, reflow oven energy consumption increases as well.

This research work is focused on the potential opportunity to reduce higher energy requirements with the use of modern thermal profiling and process optimization software.

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Keywords:
Lead-free, reflow, energy consumption, thermal profiling, process optimization.

Introduction

In order to determine the energy consumption during the lead-free reflow process, a convection oven was equipped with a multifunctional energy meter. Measurements were performed over a period of several days, during which the oven processed leaded and lead-free versions of the same product respectively.

Experiment description

The experiments were conducted using a Heller 1912 EXL reflow oven manufactured in July 2005, and a SlimKIC 2000 profiler equipped with Auto-Focus optimization software.

For the tests, a representative product was chosen from the telecom family group of products that was scheduled to be converted to lead-free in the near future. A comparison was performed on the same product manufactured in both technologies. The experiment consisted of four sets of measurements:

- leaded product with non-optimized reflow profile
- leaded product with optimized profile
- lead-free product with non-optimized reflow profile
- lead-free product with optimized reflow profile

Care was taken to make sure that no optimized oven recipes used a conveyor speed slower than the slowest cycle time in the production line.

In other words, the reflow oven did not become the bottleneck in the production line for any of the tests in this report.

Case A – Non-optimized leaded profile

For the non-optimized profile a recipe was chosen manually that fit the process window in terms of peak temperature. Based on the solder paste, substrate and components, the process window for peak temperature used the range from 205° to 225°C.
Once the profile had been set, the hourly energy consumption at the oven was measured.
As is typical, the data were fluctuating somewhat, but the average energy consumption for Case A was 10.4 kWh.

Case B - Optimized leaded profile

The optimized profile was created with the help of a profiling software system with an Auto-Focus option. This automatic prediction optimizer has the ability to pick up the lowest available peak temperature that fits into the process window. Before engaging the software, the Case A profile above was chosen as the starting point.

What can be observed at first glance is that both the peak temperature and the delta T across the board are significantly lower.

Once the profile had been set, the hourly energy consumption at each oven was measured. Average energy consumption for Case B was 8.8 kWh, which is 15 percent lower than in Case A.

Case C – Non-optimized lead-free profile

The non-optimized lead-free profile was chosen in the same way as the non-optimized leaded profile (Case A).
The difference is the peak temperature.

Table 1. Oven settings for Case A were set as follows:

Zone	1	2	3	4	5	6
Setpoint	101	117	131	155	161	161
Zone	7	8	9	10	11	12
Setpoint	171	180	199	239	239	220
Conveyor speed: 95 cm/minute (37"/minute)						

Table 2. The reflow process parameters for Case A:

Peak temperature [°C]:	223.5
TAL2 [s]:	82.0
ΔT [°C]:	11.06

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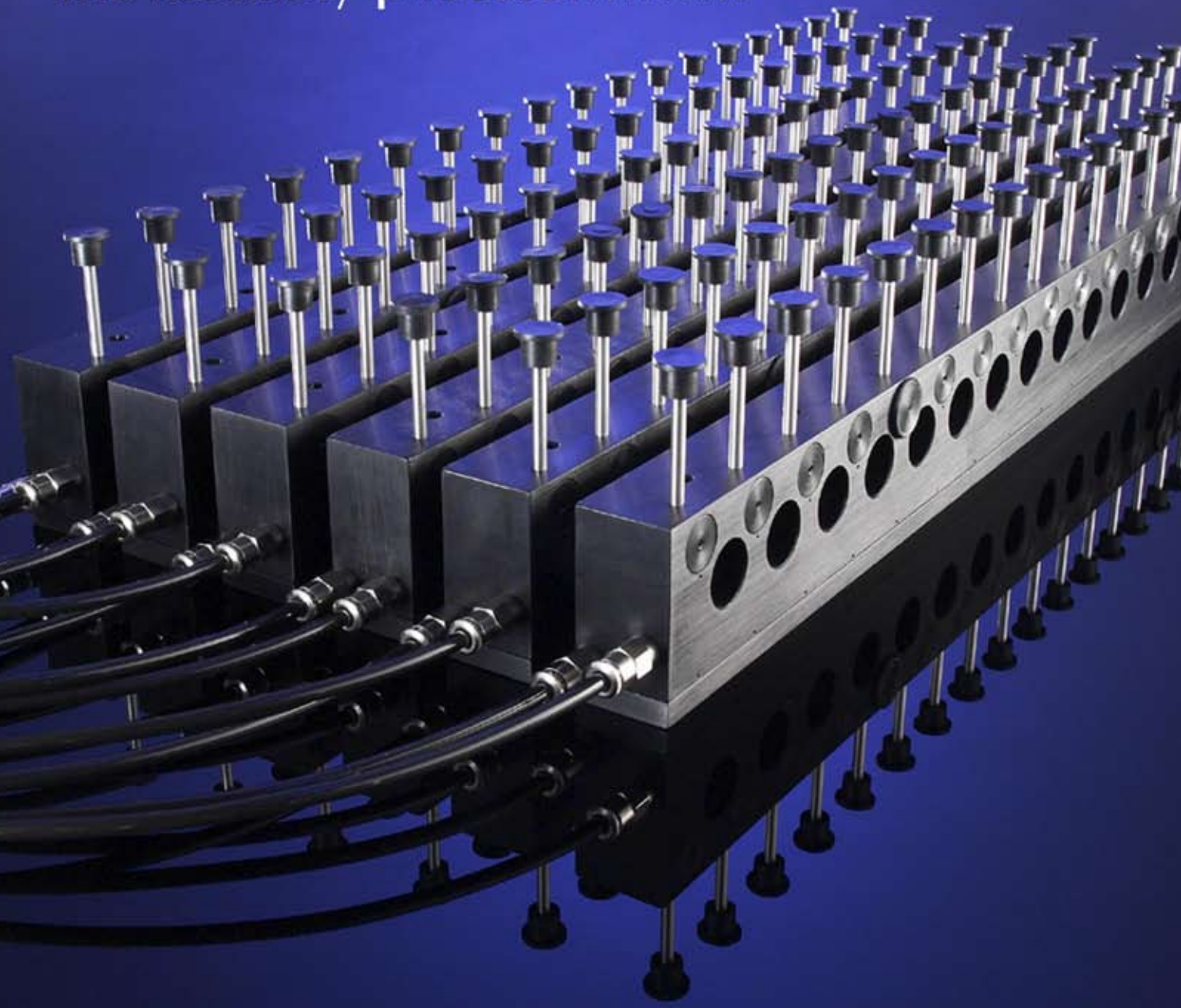

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The process window (in the terms of peak temperature) was defined as the temperature range from 235° to 260°C.

Once the profile had been set, the hourly energy consumption at the oven was measured. Average energy consumption for Case C was 11.5 kWh.

This represents a 10.6 percent increase in energy use compared to the equivalent leaded application and a 30.7 percent increase over the optimized leaded process.

Case D – Optimized lead-free profile

As for Case B, the optimization software was used to find the best oven recipe *(See Tables 7 and 8)*. We can observe significant delta T reduction.

The average energy consumption for the optimized lead-free reflow profile is 10.6 kWh. It is very similar to the non-optimized leaded profile consumption (1.9 percent higher).

Comparing the optimized lead-free profile to the non-optimized lead-free profile, there is a 7.8 percent improvement.

Conclusion

The table shows all average energy consumption for leaded and lead-free profiles. The lower usage of energy with optimized profiles can be seen.

The above numbers can simply be translated into the financial impact using *Formula 1*.

Assuming an average energy cost of $0.076/kWh, the annual energy savings per oven as a result of optimizing the process is $1,062.30 for the leaded process and $597.54 for the lead-free process.

It has been proven that using a modern thermal process optimization tool can result in production cost reduction.

An added benefit is that the optimized oven recipes do not only save energy, but they also operate in the 'sweet spot' of the process window, hence improving quality and productivity.

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References

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Figure 1. The experiments were conducted using a Heller 1912 EXL reflow oven and a SlimKIC 2000 profiler with Auto-Focus optimization software.

Table 3. The optimized oven settings for Case B were:

Zone	1	2	3	4	5	6
Setpoint	101	117	131	155	162	162
Zone	7	8	9	10	11	12
Setpoint	172	183	193	229	230	217
Conveyor speed: 92.3 cm/minute (36"/minute)						

Table 4. The reflow process parameters for Case B:

Peak temperature [°C]:	**216**
TAL [s]:	81.3
ΔT [°C]:	9.18

Table 5. The oven settings for Case C were:

Zone	1	2	3	4	5	6
Setpoint	120	130	150	179	190	222
Zone	7	8	9	10	11	12
Setpoint	235	235	243	263	262	222
Conveyor speed: 90 cm/minute (35"/min)						

Table 6. The reflow process parameters for Case C:

Peak temperature [°C]:	252.7
TAL [s]:	88.8
ΔT [°C]:	9.71

Table 7. Resulting settings:

Zone	1	2	3	4	5	6
Setpoint	116	104	140	166	193	211
Zone	7	8	9	10	11	12
Setpoint	219	231	257	247	245	208
Conveyor speed: 80.6 cm/minute (32"/minute)						

Fomula 1: Total cost of energy per year = Hourly consumption * Cost per kWh * 24 hours * 7 days * 52 weeks

Table 8. Results:

Peak temperature [°C]:	241.4
TAL [s]:	85.0
ΔT [°C]:	4.67

Table 9. Conclusion.

	Leaded	**Lead-Free**
Non optimized	10.4 kWh	11.5 kWh
Optimized	8.8 kWh	10.6 kWh