Experience

with vapor phase soldering device

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A system using resistive heaters is described. Temperature of soldering liquid increases to boiling point temperature and keeps liquid temperature at boiling temperature a few seconds. The melted solder paste joined electronic elements with printed circuit board lands. The system uses cold liquid with hot liquid mixing to cool down. The melted solder paste condensed to create soldering joint.

Soldering is a process of joining metallic surfaces with solder, without the melting of the base materials [1]. The two metallic parts are joined by a molten Filler metal. Vapor phase soldering (VPS), also known as condensation soldering, has gone through changes in popularity. It was the process of choice in the early 1980s.

VPS uses the latent heat of liquid vaporization to provide heat for soldering. This latent heat is released as the vapor of the inert liquid condenses on component leads and PCB lands. In VPS, the liquid produces a dense, saturated vapor that displaces air and moisture. The temperature of the saturated vapor zone is the same as the boiling point of the vapor phase liquid. As far as it is known this fluid does not have any environmental concerns. The peak soldering temperature is the boiling temperature of the inert liquid at atmospheric pressure.

VPS does heats uniformly, and no part on the board (irrespective of its geometry) exceeds the fluid-boiling temperature. The process is suitable for soldering odd-shaped parts, flexible circuits, pins, and connectors, as well as for reflowing tin/lead and lead-free surface mount package leads.

The key advantages of vapor phase soldering:

- Soldering in oxygen free environment (eliminates the need to use nitrogen).
- Lower peak temperature making possible to reduce the cost of PCB by 10-15% by using the substrates with lower thermal resistance and to avoid overheating the components. Guaranteed control of the max. temperature in the oven due to the physical properties of the liquid used - typically 230°C for Lead Free and 200°C for Sn/Pb boards.
- Better heat transfer to the PCB due to the use of liquid for that and not air and nitrogen. This reflects in considerable reduction of electrical power consumption. The maximum power consumption of exampled smallest oven is 3,5 kW, while the average consumption during soldering is 1,5 kW. The maximum power consumption of exampled large inline oven is 12 kW, while the average consumption during soldering is 6 kW.
- Flexible and easy control of the PCB temperature until reaching the reflow values.
- Faster and easier profiling.
- Smaller footprint in comparison with convection ovens.
- Reduction of the voids in the solder joints. For further decreasing the amount of voids, a vacuum section can be added to the vapor phase systems.
- Most complex and demanding PCB's can be soldered with ovens that cost less compared to the forced convection ovens.
- The number of soldering defects is usually smaller.

Research problem

Vapor Phase soldering was banned of lead and other potentially hazardous substances with the introduction of RoHS. The industry was forced to change over to new solder alloys, a lot of articles researched about lead-free soldering. Some important characteristic different between tin-lead and lead-free are:

- Tin-lead Paste melting point temperatures lower than lead-free Paste melting point temperatures peak temperatures.
- The wetting force of lead-free solder is not as strong as for the tin-lead solder.

Higher reflow temperature will more stress components and the PCB. Logistics of lead-free and lead components was discussed. It is very likely that defect levels will increase. All defect types that occur today should be expected but there might be a modification to their frequency. Tomb stoning, misalignment, opens, shorts and voiding have increased.

Requirements of device

A solder reflow process follows an optimized temperature profile to prevent the board from experiencing high thermal stresses while it is undergoing reflow. A typical reflow temperature profile would consist of the following steps [2]:

- Preheat, which consists of gradually ramping up the temperature to the preheat zone temperature at which the solvents will be evaporated from the solder paste
- Flux Activation, which consists of bringing the dehydrated solder paste to a temperature at which it is chemically activated, allowing it to react with and remove surface oxides and contaminants
- Actual Reflow, which consists of ramping up the temperature to the point at which the solder alloy content of the solder paste melts, causing the solder to sufficiently wet the interconnection surfaces of both the SMD's and the board and form the required solder fillet between the two; the peak reflow temperature should be significantly higher than the solder alloy's melting point to ensure good wetting, but not so high that damage to the components is caused
- Cold down, which consists of ramping down the temperature at optimum speed (fast enough to form small grains that lead to higher fatigue resistance, but slow enough to prevent thermo-mechanical damage to the components) until the solder becomes solid again, forming good metallurgical bonds between the components and the board.

Table 1. Lead free reflow profile [3]

Profile feature	PB-free Assembly
Average ram up rate	3°C/sec. max
Preheat	
Temperature Mn (t_{smin})	150°C
Temperature Mmax (t_{smax})	200°C
Preheat time (t_s)	60-180 sec.
Reflow	
Peak temperature (t_p)	220 – 230 °C
Time from preheat to peak	60-150 sec.
Time at peak temperature (t_p)	10-40 sec.
Ram-Down rate	60C/sec. max
Time from peak temperature to 25°C	8 min. max

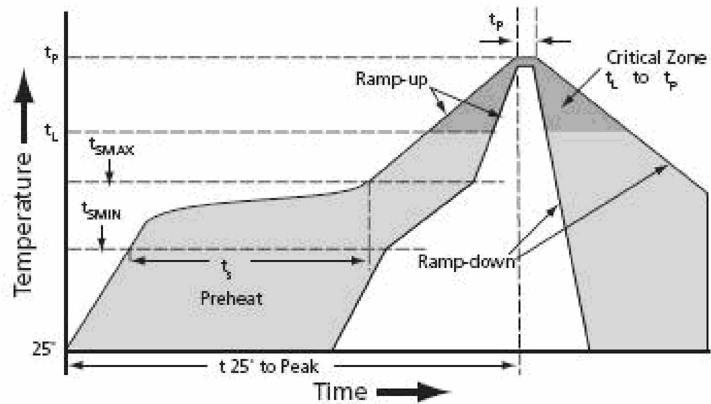


Fig. 1 Lead free reflow profile [3]

The reflow temperatures required by Pb-free board assemblies are higher than those required by non-Pb-free boards, mainly because Pb-free solders generally have higher melting temperatures than Pb-Sn solders. As such, the optimization of the reflow profile is more critical in Pb-free assemblies with regard to preventing the occurrence of package cracking in the surface mount components on the board.

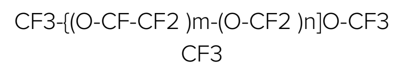
Automated soldering device with resistance heater

The major parts of this oven are the Soldering Tank, Main frame, Electric Heater, Temperature Sensor, Temperature Indicator, Cooling Device, and Controller.

Supply energy calculation for heater

Within the vapor-phase soldering system, the liquid chosen for soldering determines the peak temperature of the board [6]. The preferred peak temperature for applications of Pb-Free/no-clean solder pastes is 220-240 °C.

From peak temperature we chose liquid low molecular weight perfluoropolyether (PFPE) fluids having the general chemical structure of:



CF3-{(O-CF-CF2)m-(O-CF2)n]O-CF3
CF3

PFPEs have exceptional thermal and oxidative stability, as well as extreme chemical inertness. Their non-reactivity, high dielectric strength, low toxicity, non-flammability and non-solvent features make PFPEs ideal for electronic reliability testing including thermal shock and hermetic seal testing [7].

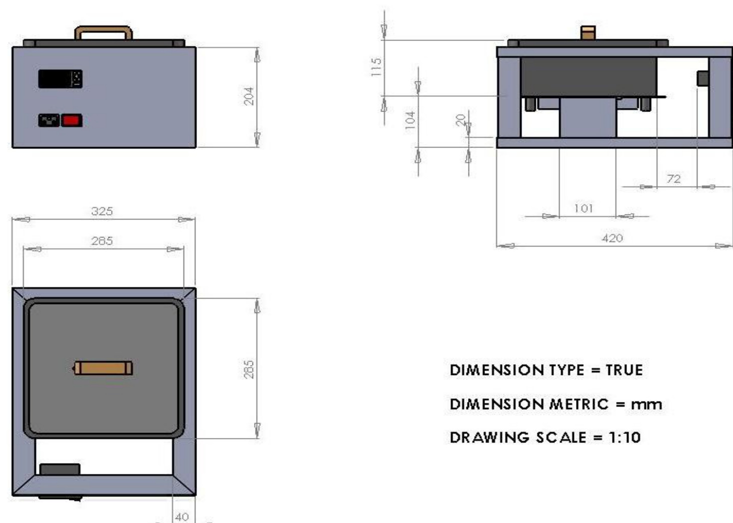


Fig. 2 Structure of automated device with resistance heater [4], [5]

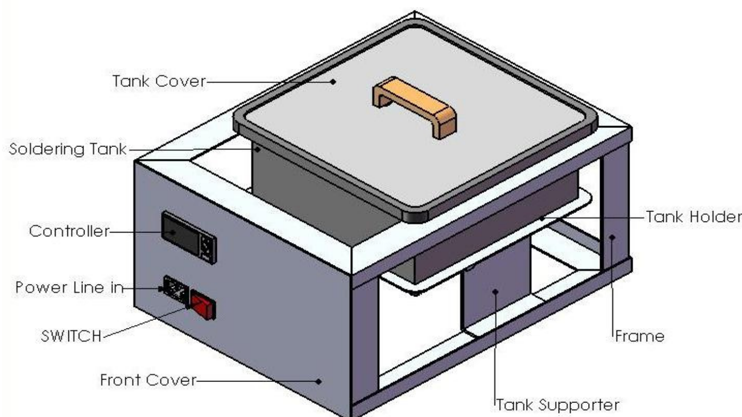


Fig. 3 Structure of automated device with resistance heater [4], [5]

Table 2 Properties of PEPE [7]

Typical Property	Units	D05
Boiling Point	°C	230
Pour Point	°C	-77
Density ρ	25°Cg/Cm3	1.82
Density, -54°	Cg/Cm3	1.98
Kinematic Viscosity 25°C	cSt	4.4
Vapor Pressure, 25°C	Torre	<1
Specific Heat, 25°C	cal/g°C	0.23
Heat of Vaporization C_1	cal/g	0.15
Thermal Conductivity	Watts/cm°C	0.0007
Coefficient of Expansion (°C)	Cm	0.0011
Surface Tension, 25°C	dynes/cm	20
Solubility of Water	Ppm(wt.)	14
Solubility of Air	Cm3	26

Control process of vapor soldering device

The controller of the device is organized as follows. Because the time constant of the device is large it will probably not be possible to control this system in a closed loop.

For this reason we are not using closed loop control. The steps of the tests are:

Step 1: Supply energy for heater with power 514 W in 43.3 second to increasing liquid temperature from 20°C to 150°C.

Step 2: Supply energy for heater with power 1028 W in 13 second to increasing liquid temperature from 150°C to 230°C.

Step 3: Supply energy for heater with power 112 W in 15 second to keep liquid temperature at 230°C

Step 4: Cooling hot liquid by cold liquid with speed 6.1 ml/second in 18 second to cooling hot liquid from 230°C to 120°C.

This is the process in theory. But practical results are somewhat different because there is the influence of heat transfer to environment and latency of heat transfer. To measure the real temperature profile, we used 5 thermocouples type K, and Labview software.

If we use volume v = 0.1L of liquid and preheat to temperature t_{smin} = 150°C with speed $v(t_{smin})$ =3°C/second the required energy is:

$$P1 = m \cdot C \cdot v(t_{smin}) = \\ = v \cdot \rho \cdot C \cdot v(t_{smin}) = \\ = 100cm^3 \cdot 1.82g/cm^3 \cdot 0.23cal/g°C \cdot 4.1\,J/cal \cdot 3°C/s = \\ = 514W$$

Preheat time is T1 = 43,3seconds

The required energy to heat from 150°C to peak temperature tp = 230°C with speedv(t_p) = 6°C/s is:

$$P2 = m \cdot C \cdot v(t_p) = v \cdot \rho \cdot C \cdot v(t_p) = \\ = 100cm^3 \cdot 1.82g/cm^3 \cdot 0.23cal/g°C \cdot 4.1\,J/cal \cdot 6°C/s = \\ = 1029W \quad (2)$$

T2= (230-150) / 6 = 13,3 seconds

Required energy to keep the liquid at boiling point is

$$P3 = m \cdot C_1 = 100cm^3 \cdot 1.82g/cm^3 \cdot 0.15cal/g°C \cdot 4.1\,J/cal = 112W \quad (4)$$

where C_1 is Heat of Vaporization of liquid.

To cool down from t_p=230°C to 120°C with speed 6°C/s by adding cold liquid with temperature t_C=20°C, the average flow of cold liquid poured to hot liquid is

Energy of hot liquid

$$Q_1 = m_1 \cdot C \cdot t_p$$

Energy of cold liquid

$$Q_2 = m_2 \cdot C \cdot t_C$$

Energy of mix liquid

$$Q_3 = (m_1 + m_2) \cdot C \cdot t_3$$

Similarly we can calculate the required volumetric flow of the cold liquid to achieve a desired cool down rate.

As a result we came to the following conclusion. Soldering device with resistance heater increases quickly liquid temperature to the peak temperature. It is easy to build the device. But this device is difficult to control in a closed loop because of the large thermal capacity = large time constant as the heater continues heating when power disconnected. The temperature at the heater is higher than the liquid so energy continues transform to the liquid. And it is difficult to cool down with a sufficient rate because volume of cooling liquid is limited. As the energy is accumulated in the tank, when cold liquid is poured into the cold one, the temperature decreases as expected, but the accumulated energy in the tank starts to heat up the cold liquid immediately. Therefore, there is

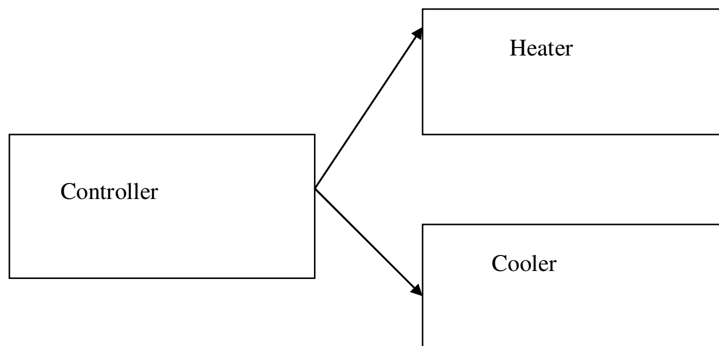


Fig. 4 Block diagram of the device

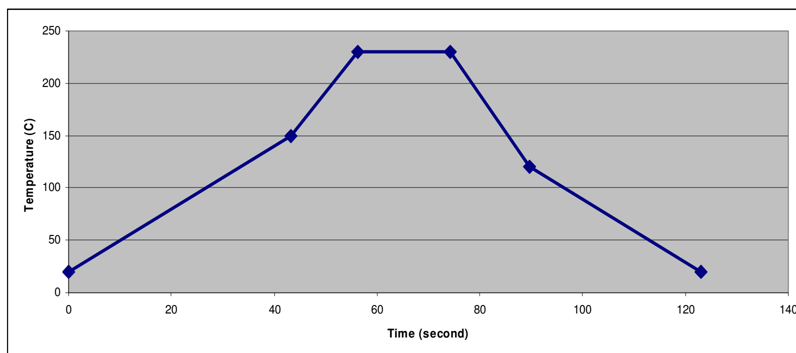


Fig. 5 Required temperature profile

a temperature rise as can be seen from the measured temperature profile. For this reason, a construction of another device is now in progress that should eliminate this disadvantage.

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RESUMÉ

RESUMÉ

V článku je popisován pájecí systém pro pájení v parách inertní teplovodivé kapaliny. Systém používá odporový ohřev a chlazení směšováním studené a horké kapaliny. Pájené spoje jsou realizovány pájecí pastou, která je ohřívána parami teplovodivé kapaliny.