Today's Vapor Phase Soldering
An Optimized Reflow Technology for Lead Free Soldering

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ABSTRACT

In the beginning of SMT, Vapor Phase Soldering was the preferred reflow soldering technology because of its excellent heat transfer capabilities. There were also some disadvantages like fast temperature rise, nearly no influence on the temperature profiles and high costs. So the use of Vapor Phase Soldering was reduced to special applications with high mass or complex boards in low numbers (e.g. for military or aerospace use).

Over the last years a new Vapor Phase procedure and new machines were developed. So Vapor Phase Soldering now offers new features for soldering, especially helpful when changing to lead free soldering. The main advantages of a state of the art vapor phase system are low process temperatures, freely adjustable temperature gradients and profiles, automatically controlled time above liquidus and a perfect automatic inert gas atmosphere.

Soldering always means to heat up everything good enough that soldering can be accomplished even on sockets or large BGAs but at the same time to be sure that nothing is overheated or delaminated. So especially for lead free soldering the process window becomes pretty small. With Vapor Phase Soldering even FR4 boards, double sided densely packed, can be soldered reliable and with no danger of overheating since the maximum board temperature is physically limited to the vapor temperature (e.g. 230°C for lead-free SnAgCu).

Because of its perfect inert gas atmosphere the wetting with lead free solder paste, is almost as good as with leaded solder alloys. Latest developments in vapor phase soldering technology provide a combination of Vapor Phase and vacuum soldering to get void free solder joints. This vacuum soldering technology becomes increasingly important since more and more power electronics need to be soldered on SMT boards.

The advantages of the Vapor Phase heat transfer in combination with new machines and options offer an excellent tool for easy and defect free reflow soldering, independent whether lead free or leaded solders are used.

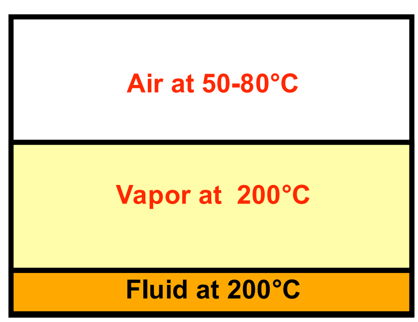
1. HISTORY OF VAPOR PHASE
1.1 MACHINES

The procedure was invented by Dr. Pfahl at Western Electric in 1974. Vapor Phase was widely used in the industry of the early Eighties. Vapor Phase soldering was the process of choice in reflow soldering as it provided the easiest way of heat transfer for the newly developed SMD technique. The soldering of SMT boards was very convenient when using Vapor Phase because of its excellent heat transfer capabilities. The vapor phase ovens were pretty long and heavy though. The boards were going through the different heat levels inline with a constant speed. The ovens were consuming large amounts of gas and liquids that in addition were critical to the environment. The industry was working on alternative solutions and with the ban of CFC, IR and convection became popular. After that, the use of vapor phase was limited to difficult solder jobs with heavy mass components or boards with a mix of high and low masses.
Only a few engineers were realizing the big potential of vapor phase and developed new technologies, equipment and liquids.

1.2 TEMPERATURES

To ensure good quality solder joints and areas, a vapor phase oven provides temperatures just above the melting point of the solder alloy used for production.

Leaded solder was the standard for almost all electronic SMD soldering in the past. This solder was eutectic and had a sharp melting point at 183°C (361°F). The materials for the PCBs, the plastics for the components and the equipment were meeting the requirements of the leaded solder process pretty well due to the large experience over a long period. The process windows were big enough to provide a sufficient soldering result with acceptable thermal stress to the electronic parts.
In a vapor phase process, typically a fluid with a boiling point of 200°C (392°F) was used and thus induced lower thermal stress in comparison to the convection process.



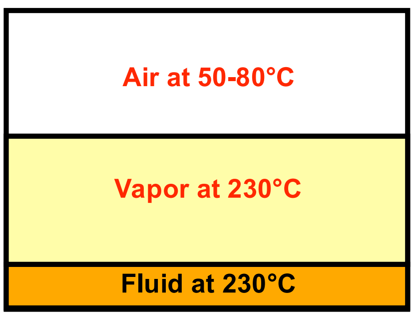
Vapor Phase temperatures for leaded soldering

The conventional soldering process became critical with the ban of lead and other potentially hazardous substances with the introduction of RoHS. The industry was forced to change over to new solder alloys, which in general have significantly higher melting points. Because of various patents on these new solder pastes, the lead free solder alloys were not creating one single new standard. Thus the use of different mixtures with different melting points became the situation of today. The most common lead free solder is SnAgCu such as SAC305. The melting point is between 217°C (423°F) and 221°C (430°F). In a vapor phase system such solder pastes are processed with peak temperatures of 230°C (446°F).

Another widely used solder is the cheaper SnCu solder alloy with a melting point of 227°C (440°F). In vapor phase the use of a fluid with a boiling temperature of 240°C (464°F) was recommended.

Following the request of various companies to limit the maximum temperatures to 235°C (455°F), as mentioned in IPC standards, a smooth soldering liquid with a boiling temperature of 235°C was introduced.

This liquid works of course also perfect with all range of typical solder temperatures from 217°C to 227°C.



Vapor Phase temperatures for lead free soldering

The physical solder temperature limitation in a vapor phase machine reliably prevents overheating of any part in the solder process. As the vapor due to its high density is heavier than the surrounding air, the soldered parts are constantly sealed within an inert atmosphere and at the same time the wetting of the parts is supported by these conditions. The air above the vapor phase is cooled down to temperatures of 50°C to 80°C only.

2. TODAY'S VAPOR PHASE

2.1 MATERIALS

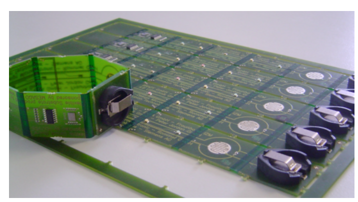
The introduction of new solder alloys along with higher process temperatures is the core challenge in the transition towards lead free soldering.

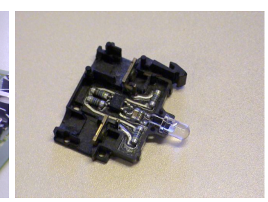
Lead free solder pastes show reduced wetting properties asking for an oxygen free atmosphere. To support wetting and avoid oxidation of the electronic components due to the increased process temperatures, conventional convection systems require nitrogen gas for the soldering of high quality electronics. In vapor phase soldering the process itself provides such atmosphere and thus additional protective gas is not required.

The substrates used for PCB boards have not significantly changed. FR4, an epoxy compound, is the main board substrate used in single and multilayer designs. These substrates are heat sensitive and tend to delaminations on higher temperatures. As with other failures in electronic manufacturing such delaminations are difficult to detect with standard inspection systems. With such defects, the electronic units might function right after production, but fail after a short period. Vibrations and temperature variations further increase the failure ratio.

The plastics used for bodies, housings and in many substrates show similar thermal problems. The set up of components also did not change much during the transition to lead free soldering.

Electronic components in general are getting more powerful on the one hand, and smaller in size on the other. They need higher accuracy in all assembly processes like solder printing, placement etc. In addition it holds true that the smaller the components, the more expensive they are to check. Soldering quality under BGAs and other modern components cannot be sufficiently surveyed without expensive equipment such as x-ray. If they are not processed correctly at the first time, rework is becoming costly and time consuming. LED technique is replacing conventional bulbs and fluorescent lamps. Small in size, they are very energy efficient. For a long life, the board design allows them to transfer their heat on the PCB boards, which in turn asks for metal core boards. This combination of heavy mass and small components is the utmost pain for conventional convection soldering. Looking at today's materials in the electronic business, again vapor phase sets the standard in quality with its low temperatures, equal heat distribution and perfect wetting properties.





Modern vapor phase systems are made of stainless steel and aluminum. It is important to use high quality connectors and cables, especially when they are exposed to some heat.

2.2 FLUIDS

Modern vapor phase heat transfer fluids are based on perfluoropolyethers and do not contain any CFC or other harmful ingredients. Its main properties are chemical and thermal resistance, non-toxicity (it can be found in cosmetics and as a blood replacement substance), excellent electric insulation properties, no flash or fire point, and low viscosity.

With these excellent attributes, there are no limitations for transportation and storage of these liquids.

The most common liquids are (boiling point in brackets):

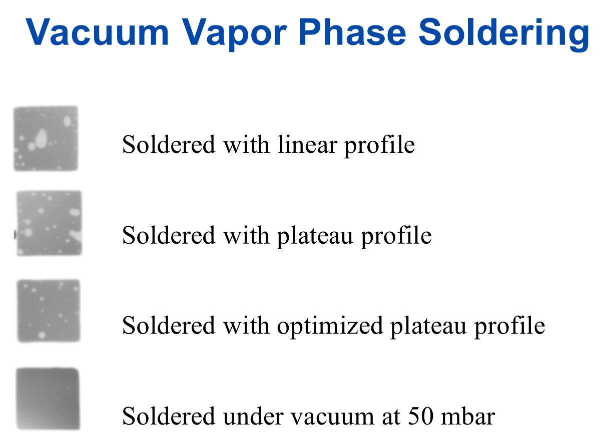
Leaded soldering	LS 200 (200°C)
	LS 215 (215°C)
Unleaded soldering	LS 230 (230°C
	HS 240 (240°C)
and new	IBL 225 (225°C)
	IBL 235 (235°C)

In case there is no exact information on the solder used for BGAs or other important components of a board, pre-tinned PCB boards etc., the recommendation is to use a 235°C boiling point. This provides the best compromise for all lead free applications and best possible results.

2.3 MACHINES

There are a number of machine types and manufacturers on the market. They offer different solutions in a wide range of machine sizes, starting from small laboratory equipment for prototyping, testing and rework, over mid-size batch up to inline machines for high volume production. Some of the batch machines can be upgraded to inline use later as it might be needed.

When outstanding quality is needed and voids in solder joints or solder areas must be prevented, vacuum vapor phase machines are the solution.



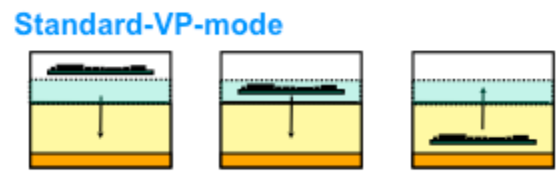
IR for preheating can be helpful to shorten process times or for glue hardening, although this can be all done in the vapor as well.

In General, vapor phase ovens have a small footprint so they need less space than a comparable convection oven. The energy consumption is by far the lowest of all reflow-soldering methods.

3. CONTROL OF VAPOR PHASE HEAT TRANSFER

3.1 CLASSICAL HEAT TRANSFER IN ANCIENT VAPOR PHASE SYSTEM

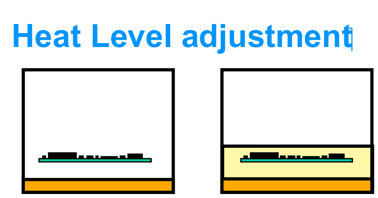
The first vapor phase machines gave users not many options to control the temperatures on the boards. The boards were transported inline through the machine. The temperature gradients were high which was critical for many components and boards due to varying expansion coefficients of the different materials.



The PCB boards are moved into the vapor where they heat up and solder
A protective layer reduces too high temperature gradients and reduces fluid consumption

3.2 HEAT TRANSFER CONTROLLED BY HEAT LEVEL ADJUSTMENT

A first step to have a temperature control was to adjust the temperature gradients by regulation of the power for the heating elements. The more power is put on the heaters, the more vapor is produced and the more heat will be transferred at the same time. The boards are positioned just above the fluid and remain there for the time of heating and soldering. The raising vapor creates an inert atmosphere. The boards are heated and soldered in an oxygen-free atmosphere. Less oxide means better wetting in return. This machine concept influences the machine design as well and allows a very compact footprint.
Despite the drastically increased benefits of this machine concept, a slight time delay in the heater control prevents the creation of sophisticated temperature profiles. The effect is known from a boilerplate, with a pot of water. After turning on power, it takes some time for the water to boil; in return after switching off the power, the water continues to boil for a while.
Thus the heat level adjustment is suitable for linear temperature profiles, as soon as temperature plateau profiles are required for soldering complex boards, this technology reaches its limits.

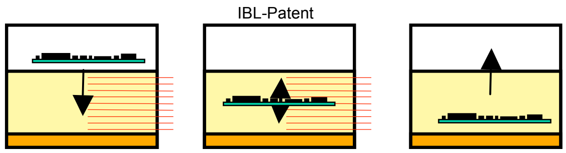


The PCB boards are moved into the VP chamber and the heat is controlled by power with raising vapor level

3.3 HEAT TRANSFER CONTROL BY LEVEL ADJUSTMENT (SOFT VAPOR PHASE)

The next evolution in heat control was the introduction of soft vapor phase (SVP). This patented process is controlling the heat transfer by adjusting the penetration level of the solder goods in the vapor.

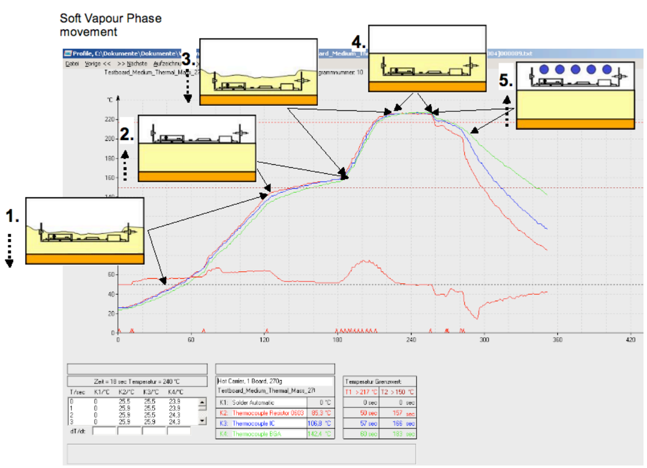
Soft Vapor Phase (SVP) mode



The PCB boards are moved into different levels in the vapor up and down. This allows to create all kinds of profiles

The benefit of this procedure is the immediate temperature gradient control as a function of the height level of the boards. Any temperature gradient or plateau can be realized and a process control surveys the process to ensure exact repeatability. The creation of plateau temperature profiles reduces voids significantly, prevents tombstoning and avoids the introduction of thermal stress.

Soft Vapor Phase



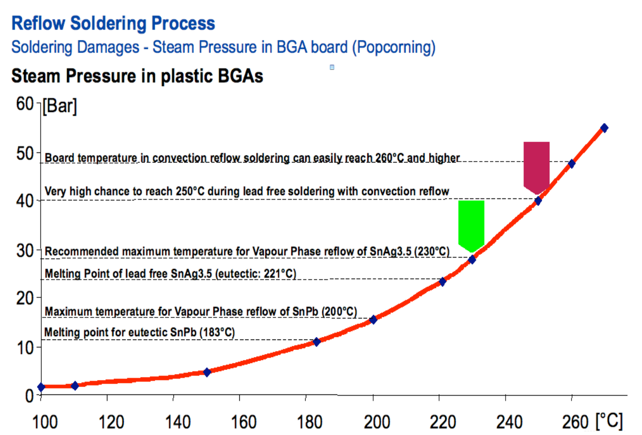
The graphic above shows the different stages of the SVP process. In the first step the PCB is moved into the vapor and the board temperature increases. The second step is activated as soon as a preset plateau temperature is reached, in the sample above it is 150°C. To achieve this, the PCB is moved up to the vapor boundary. After a soaking time of 60 sec. the PCB is moved over dedicated levels downwards, controlling the gradient and reaching the soldering temperature. The soldering time (time over liquidus) can be pre-selected and is controlled by the solder automatic, thus limiting the temperature introduction to a minimum and still ensuring a thorough soldering result.

4. CONCLUSION

Convection is today´s most common reflow soldering process. For many applications it is provides acceptable results. The machines are usually designed as inline machines with straight board handling for high throughput.

Vapor phase soldering has become competitive also for high volume productions. State of the art machines offer high throughput in combination with high quality results. The vapor, like all gases, is tending to equally fill out a given sphere, such as a vapor phase process chamber. The equal temperature distribution over the boards is automatically provided by this physical effect, while in a convection oven the cross profile can vary in temperature. The physical limitation of the maximum temperature in a vapor phase system does not require further controlling mechanisms to avoid overheating. This quality feature is also today providing highest benefits in long-term reliability of the soldered electronic boards. In a convection oven the creation of temperature profiles needs thorough preparation, overheating cannot be securely avoided especially on boards with varying mass distribution.

The excess heat needed to ensure a perfect solder result in vapor phase soldering is only 5°C to 10 °C over the melting point of the solder paste. Other reflow methods require 30°C to 35°C excess heat for the same task due to its lower heat transfer rate.
Lower soldering temperatures are limiting the stress for the components, avoid delaminations on PCB substrates and limit the risk of popcorning on modern components.



The vapor phase process provides an oxygen free atmosphere at no extra cost leading to the best possible wetting. The energy consumption (typically 5-6 kW for a large inline system) is much lower then convection as the energy remains in the hot liquid. Optimized insulation reduces the introduction of heat into the surrounding and thus enables to save air conditioning cost in the plant.
Vapor phase ovens are smaller than convection ovens, thus they also save space in production.
Considering today´s and future complex components and processes, vapor phase is a perfect choice.

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