Condensation Reflow-Soldering

The Soldering Process with Solutions for future Technological Demands.

Speaker: Claus Zabel
ASSCON Systemtechnik-Elektronik GmbH
Germany

ASSCON Systemtechnik-Elektronik GmbH
Messerschmittring 35
D-86343 Königsbrunn
Telefon: ++49 (0)8231/95 99 1-0
Telefax: ++49 (0)8231/95 99 1-90
E-mail: info@asscon.de
http:\\www.asscon.de

TABLEOF CONTENTS **PAGE**

1 Background

The modern production of electronic assemblies in SMD-technology is unthinkable without the efficient printing process, placement process and particularly the soldering technology. In particular, for a high and constant product quality the soldering technology is of utmost importance.
From the start of the SMD-technology there have been two processes competing constantly with each other. There is the vapour-phase soldering process – which has its origin in a patent granted to the Western-Electric Corp. in 1974. And there is the infrared-soldering process. From the start of the SMD-technology the vapour-phase soldering process was ahead, as the available soldering systems for the infrared technology could not meet the required production quality. Inspite of several - however grave disadvantages - the vapour phase process was widely used. Its main advantages were already then the exact, limited end-temperature, a totally oxide-free soldering process as well as a very homogeneous heating and temperature distribution on the printed circuit board. Yet, this now outdated machine technology contained also several very grave disadvantages:

- To prevent high losses of the vapour-medium, CHFC-covers were installed - quasi as lids (CHFC problem).
- At the interface between the vapour medium and the CHFC -cover a mixture-layer was created, which resulted in decompositions - creating acids (hydrofluoric acid and hydrochloric acid).
- The operational costs for the machines were very high (high medium and FCKW consumption).
- The acid creation and CHFC -cover resulted in enormously high maintenance overheads.
- The machine size - compared to its production capacity - was gigantic.
- At the beginning the machines had no additional pre-heating, thus creating extremely high temperature gradients during soldering..

In due course the technology for the infrared machines advanced. Consequently, these machines started to produce a good to very good solder-quality. The design of these machines – compared to the vapour-phase soldering machines – was far less complicated. Furthermore, the costs to operate these IR-machines and their necessary maintenance were well below those of a vapour-phase soldering machine.
The market-share of the vapour-phase soldering machines declined constantly, due to the rapidly improving alternative soldering systems. The end of the 2-phase vapour-phase machines came when CHFC‘s were prohibited.
Now, as the assemblies become even more complex and the shapes of components changed, the IR soldering technology faces substantial limits. Consequently, with the furthere advances in convection soldering technology it is these machines which have become established in the market. Compared to the infrared machines they offer substantial solder-quality advantages.
However, inspite of the decline of the vapour-phase technology with the well-known manufacturersr, there have always been a few small companies that tried to cash in upon the the principal advantages of the vapour-phase soldering process. They tried to come up with a more advanced machine technology, which eliminates the disadvantages of the old system and consequently to revive this process. Thus, these systems continued to be used by producers in niche-productions. They succeeded particularly well in laboratories and in the production of samples. The new concepts of this machine technology as well as its constantly superb soldering-results is leading gradually to the conviction that the rather bad reputation of the vapour-phase in idustrial production might not be fully warranted. After this change of mind in the industry to return to the vapour-phase technolgy, machines are designed for ever larger productions. Already now they produce smaller to medium-sized quantities of unsurpassed quality.
Meanwhile the vapour-phase has become a fully accepted mass-production soldering process, particularly in regards to the newly introduced component technologies, e.g. BGA`s or the new production shapes as 3-D printed circuit boards.
Todays vapour-phase technology solders any kind of solder-product - with minimum expenditure or effort and with the best possible solder quality. The different machine models make it possible to cover the whole production spectrum – from the laboratory to small and medium-sized series - all the way to the big inline systems with highest throughputs!

Todays State of Technology

The design advances of the machine technology for the vapour-phase process result in machines which have nothing whatsoever in common with the former units of ill repute. Todays vapour-phase soldering machine is an environmental friendly, very economical system – based upon the physical lasws of the heat-transfer with vapour. Its process ensures mearly automatically the highest possible solder-product quality.

The main advantages are:

- Pre-heating of the solder-product irrespective of shape, colour, dimensions and mass-distribution.
- A totally oxygen-free environment without using protective gases.
- Maximum defined end-temperature of the printed circuit board – due to limited vapour-temperature.
- Freely pre-selected temperature gradient during the entire heating process (TGC Controlling).
- Automatic identification of the soldering temperature and thus shortest possible time above the liquidus (ASB).
- Absolutely unique and totally void-free soldering process - even with extremely large area solder-joints in combination with a vacuum-system (Void free vacuum soldering process).
- Smallest temperature difference on the assembly.
- Lowest damage potential of all soldering processes.
- Lowest operation costs at highest solder quality.
- Optimally suited for lead-free soldering processes.
- The vapour-phase environment works like a distillation column and is totally free of any volatile fluxes or solvent vapours. Therefore, the printed circuit boards are clean after soldering. Bonding may be performed immediately after the soldering process.

2 Different concepts of vapour-phase soldering machines

2.1 Different modes of vapour principle

2.1.1 1-Phase-machines with saturated vapour

This process is based on a patent from AT&T Corp. The principle of the saturated vapour is quite simple: Over a boiling fluid there will be a build-up of saturated vapour. Due to its extremely high density it hovers well defined on the boiling fluid. The temperature of the vapour always equals the boiling temperature of its fluid. As soon as a printed circuit board enters this vapour, the vapour condenses until the PCB has reached the vapour temperature. After the PCB leaves the vapour-zone it must be dried as there is still a film of fluid on it.

2.1.2 2-Phase-machines with saturated vapour

There is only one fabricator world-wide who uses this system. Its technology is based on previous vapour-phase soldering machines which operated under CHFC-cover. The idea is to replace the original CHFC -cover with a low-boiling medium which has the same properties as the fluid used to produce the actual soldering-vapour. Because of the different densities created by the two vapours, there will be an interference between the hot vapour and the cooler vapour. Due to these two differently available temperatures it is called the 2-phase system.

However, as the substantial disadvantages, e.g. high medium-consumption, high maintenance overheads, low production rates, etc., have not been eliminated, the process is not successful in the market.

2.2 Differentiation according to machine type

The differences between the soldering systems in the market which operate with different vapour production methods, may be extended also to within the machine technology. Basically, two machine systems are used:

Laboratory systems:
Laboratory systems are used best for laboratory work and sample productions. Most difficult repair work may be performed too, using an optional de-soldering system.
One of the main application areas is the testing and qualification of new pastes, printed circuit boards components, etc.
The material in-coming quality-control may very quickly check, e.g. the quality of supplied pastes and other materials with wetting and solderballing tests.

Batch- or stand-alone machines:
Their main application is the production of samples and small series. These machines feature a state-of-the-art vapour-phase soldering process, i.e. pre-heating, soldering, drying, cooling. As a rule the loading of the machine and starting of the soldering process is done manually by its user. These batch machines may be additionally equipped with an autimatization system. This makes it possible to fully automate the machine‘s soldering process for certain products.

Most of the batch machines may be equipped with automatization units and may consequently be integrated into any automatic production process. The selection of the suitable model has to be in accordance with the the requirements of the respective production and the nature of the solder product.

Inline machines:
The new inline-condensation-reflow-soldering machines close the gap between the automatic batch units – which produce a first class solder-quality but not the required throughputs - and the convection-inline-machines for large mass production series.
Using the temperature gradients Controlling and the automatic solder-temperature identification, and designed as classical inline machine with separate conveyors for loading, pre-heating and cooling of the printed circuit boards arranged in the direction of the process, these machines may produce very high throughput.
With standard SMEMA or Siemens interfaces the machines may be integrated into any automatic inline production process without problem.
The main area of application is the production of complex boards or complicated components, e.g. ceramic BGA´s or SMD SIMM components.High-count multilayers or ceramic substrates may also be processed without difficulty.
This new technology obtains also very good results with very large mass-differences on the printed circuit boards, because the temperature variation is only very slight.
Due to the tremendously favourable efficiency value for the condensation heat-transfer, the machine requires only a very moderate energy supply. The average energy consumption is very low even when operating at full capacity.
As the respective process vapours create an oxygen-free atmosphere in the soldering-zone, the machine does not require any additional protective gases, e.g. nitrogen.
With its integrated circulating cooling system for the necessary cooling water, the machine is independent of an external water supply.

3 Description of the vapour-phase soldering process

Old State of Technology:
Initially, to vapour-phase solder an assembly was - in principle - not different to the regular classical soldering, e.g. the infrared or convection process.
The printed circuit boards were pre-heated in the vapour-phase machine via a pre-heat system, e.g. infrared or convection and subsequently conveyed to the actual vapour process-zone.
The next process-advance was the introduced by the FSL Corp. with a second pre-heating area, which already takes advantage of the existing vapour. There the printed circuit board is positioned on the upper edge of the vapour so that the vapour may reach only its lower side. This results in an additional pre-heating of the printed circuit board, thus balancing to a large degree any temperature differences, which might have occurred during its first pre-heating. Most OEMs provide this second pre-heating process in slightly modified form.
However, the main disadvantage of all these pre-heating methods remains the primary use of the IR pre-heating zones. The optimal heating process in the vapour phase is preceded by the worst pre-heating – i.e. the infrared process! Furthermore, the energy-supply process in the vapour-phase was not variable, thus causing many soldering defects. The common misconception lingers on that the old-technology vapour-phase machines offered oxidation-free soldering. As the first stage pre-heating with infrared systems gets up to approx. 150° C on the assembly a caused high oxydation on the boards has to be expected. It also resulted in extreme temperature-differences on the assemblies due to the uneven heat-transfer. Consequently, because of their high oxidation potential these old vapour-phase machines are unsuited to process lead-free pastes.

Today's State of Technology:
A milestone in vapour-phase soldering-technology was reached when ASSCON Systemtechnik introduced the variable temperature gradient control in 1997. Such machines do not need any additional pre-heating systems as now the pre-heating periods in the vapour may be variably controlled. This makes it possible to produce the heating process in the extremely homogeneous and oxygen-free vapour-zone. The solder-quality is therefore very greatly enhanced as the overall portion of oxidation in the pre-heating section does not take place. This oxidation, affected the printed circuit boards during IR pre-heating in technologically outdated machines and in particular the metallization and the paste. Hence for the same solder-quality the lowest activated pastes are sufficient. Therefore, due to the low residues of the fluxes the products are extremely clean. The removal of the IR-zones and using the energy in the vapour-phase in an optimal way, the consumption of energy and medium are kept to a minimum. Neither do today's machines need any external cooling water supply. The maintenance costs and upkeep have been reduced drastically.
In combination with automatic solder-temperature identification control (ASB) to realize the shortest times above liquidus, the vapour phase process guarantees an ideal and easily reproducible soldering process.

To pre-heat the solder-product it must be conveyed into the area of the vapour. Here the vapour condenses on the cold solder-product until the end-temperature of the vapour has been reached. The condensed vapour forms a closed film on the printed circuit board, due to the high surface tension of the primary fluid used. Further vapour condenses in this film. As the film conducts heat very well the transmitted energy is distributed very homogeneously across the assembly. This is also the reason why it is possible to heat also under large-area components with hidden solder connections.
The heating speed depends upon the quantity of the condensed vapour. The quantity of the vapour may be varied during the whole heating process, thus offering the possibility to tailor the process exactly to the requirements of the respective product.

Subsequently the product leaves the vapour-zone and the remaining soldering fluid on the printed circuit board evaporates, due to the residual energy within the board.
In the last process-step the soldered and dried printed circuit board is cooled in a cooling station.
This ends the production process.

3.1 The principle of heating by vapour and its physical laws

The whole system of the vapour production and the heating of assemblies with vapour is exactly defined by physical laws and procedural models. As the heating of the vapour-phase may be reproduced in detail, a corresponding process control may be also defined most easily.

Starting a cold soldering machine:

1. Having activated the heater the vapour-phase fluid heats up in the process tank.
2. As the machine operates under atmospheric pressure the heating of the fluid stops the moment its boiling point has been reached. (Lead containing alloys 200° C, lead-free alloys 230° C).
3. Having reached the ***boiling point***, no additional energy will increase the temperature of the liquid. Any surplus energy will cause the so-called '***phase-transition***'. The fluid changes from its liquid to its vapour '***aggregate condition***'. This 'phase- transition ' is in accordance to the law of 'vapour enthalpy'. The law states: To evaporate a certain volume of fluid at its boiling point requires an exactly defined amount of energy. The respective amount of energy is a material constant.
4. As soon as the vapour fills the process chamber, the energy supply is reduced to balance any radiation losses of the machine.

The heating process of a printed circuit board in vapour:

1. An assembly with components and solder paste is conveyed at ambient temperature into the vapour.
2. As the temperature of the printed circuit board is below that of the vapour, the vapour condenses on it.
3. The condensation is the rebound of the '***aggregate condition***' - from vapor to fluid. Having entered the vapour, a homogeneous fluid-film covers the printed circuit board within a fraction of a second.
4. This fluid-film has an exactly defined thickness depending upon the ***surface tension*** of the respective fluid. Furthermore, the film will – due to its surface tension - displace any oxygen from the printed circuit board and thus also from below the components. This creates a totally oxygen-free environment on the assembly during the whole heating process.
5. The produced film is now responsible for the heating process of the printed circuit board. As the film looses energy due to the cold printed circuit board, its temperature lies under that of the vapour. Between the film and the vapour temperature exists an energy equilibrium, the so-called '***partial pressure difference***'. The molecules of the vapour are attracted to the film as if by a magnet. As soon as a vapour molecule contacts the film it will condense. During this condensation the same amount of energy is released as was required for evaporation with the heaters (***Evaporation enthalpy***).
6. This gain of energy causes the temperature of the film to increase during condensation.
7. This results in a temperature difference in the film - from the outside to the inside. Thus the ' heat conduction' in the film transports the energy towards the assembly where it affects the heating. The transmitted energy will be distributed absolutely evenly throughout the film over the whole surface of the assembly.

The end of the heating process:

1. The end of the heating process has been reached the moment the temperature of the assembly equals that of the film and the vapour. As soon as this condition occurs, there will be an '***energy equilibrium***' in the system. This equilibrium causes the elimination of any '***partial pressure difference***' between film and vapour.
2. From this moment on no more vapour molecules condense in the film. The soldering process has ended.

Temperature compensation on the printed circuit board:

1. The temperature differences on the printed circuit boards are created by the '***mass differences***' between components and/or the different structure of the laminate (e.g. differing quantities of copper in certain areas of the assembly). This temperature difference on the printed circuit board causes the film covering the assembly to have different temperatures too. These temperature differences, however, do not occur from the outside towards the inside but in the cross-profile.
2. These differences cause the energy to flow from the hotter areas of the film to the colder – due to an ***energy imbalance*** in the cross profile of the film.
3. The film has a '***self-regulating energy distribution function***' on the assembly. Thus, extremely low temperature differences exist on the assembly during the whole heating process. These temperature difference amounts generally to maximum 5 K.

3.2 Variable temperature-gradients (TGC Temperature gradient controlling))

The demand for variable temperature gradients in the vapour-phase process may be easily met.
The gradient on the printed circuit board depends always on the supplied energy per unit of time. This means for the vapour-phase: How many vapour molecules per unit of time condense in the fluid film on the respective assembly? This amount of vapour molecules may be easily established through the vaporization enthalphy. By controlling the energy supply in the vapour generator during the heating process of the printed circuit board, it will produce only a corresponding amount of vapour per unit of time. Consequently, only this previously produced amount of vapour may condense on the assembly.
Therefore, the process makes it possible – by simply changing the energy supply in the vapour generator – to produce the gradient at the value required by the user.

3.3 Automatic identification of the soldering temperature (ASB Automatic solder break)

The vapour-phase process permits to automatically utilize its physical processes during heating to determine the point at which the soldering temperature has been achieved.
Due to the limited energy supply during soldering, fewer vapour molecules are condensing than might be possible according to the available assembly surface. Thus during heating, the upper surface of the vapour stays always at the same height as the printed circuit board. The moment the printed circuit board reaches the vapour temperature there is no more difference in the partial pressure between the fluid film on the assembly and the vapour. When the assembly has reached the end-temperature, no vapour will condense in the film – due to the equal partial pressure. However, as the heaters continue to produce vapour, the vapour in the process tank rises again. The rise of the vapour is monitored by a thermocouple and evaluated as an end-signal of the soldering process. Subsequently, the machine automatically conveys the printed circuit board from the soldering area to start its cooling.
The printed circuit board is then automatically conveyed out of the hot area of the machine, remaining only for the shortest time above liquidus.
Pre-setting a target time in which the soldering temperature must be reached, the machine controls achievement of the correct gradient and activates a warning the moment something changes.

3.4 Optical process control (OPC Optical process controlling)

The physical parameters in the vapour phase permit a very easy and simple process control that is totally reproducible. In other soldering systems it is always necessary to control or newly establish a profile with measuring devices, creating great expenses for personnel and time spent to measure the process. As in vapour phase processes the energy input during soldering is constant – thus creating a straight line with constant slope in its profile. Therefore, the process may be controlled by purely optical means.
The slope of the straight line (corresponds to the temperature gradient) is defined by the following fix-points.

Start: Room temperature as assembly temperature and the moment the product is immersed into the vapour.
End: Liquidus-point of the paste (observable when reflowing the paste) and time elapsed since the immersion into the vapour.
If the room temperature is e.g. 20°C and the paste melts 100 secs. after being immersed into the vapour – it results in the following temperature gradient:
183 degree (Liquidus temperature) – 20 degree (Starting temperature))/100 sec-□ Temp.gradient amounts to 1.63 K/sec.

3.5 Process reliability

Due to the physical laws, which govern the vapour-phase soldering process, its conditions are extremely stable. The main advantages are:

- The maximum temperature of the assembly equals that of the vapour, e.g. 200 °C. No over-heating, damage to the components, delamination is possible.
- The soldering process is 100% oxygen-free – and without additional protective gases. This results in optimal wetting- and self-centering behaviour and allows the use of mildest pastes. Bridging is a thing of the past.
- The energy distribution on the printed circuit board is extremely homogeneous. Even multi-layers with 50 layers or components with extreme mass ratios may be soldered stress-free. Three-dimensional printed circuit boards may be produced without any problem.
- The energy requirement is the lowest possible because of the high efficiency value of energy transmission with vapour. This results in low waste-heat in the production areas and low temperature stress upon the mechanical parts of the machine. The cost for power and maintenance is low.
- The process times are the shortest possible because of the homogeneous heating and because a constant gradient without dwell-times may be selected. This offers substantial advantages particularly with sensitive components.
- Due to the variable temperature gradients it is possible to tailor the soldering process optimally to the respective product parameters.
- The damage potential is the lowest possible because of the lowest process temperatures, oxygen-elimination and the absence of any radiation during the energy transmission. The failure rate is drastically reduced particularly with temperature sensitive materials, e.g. rigid-flex printed circuit boards, etc.
- Contrary to the convection machines the process parameters do not depend upon the machine. Thus, the smallest laboratory unit produces exactly the same soldering quality as the High End Systems. Consequently, the user may develop a test sample with a laboratory machine and will be sure that this product will exhibit exactly the same quality parameters in the mass-production machines. These system dependent characteristics produce a superb product-quality as well as printed circuit boards with excellent durability.

3.6 Low cost of operation and high flexibility

Because of the excellent efficiency value in the transmission of energy with the condensation of vapour, these machines require only a fraction of energy compared to e.g. convection- or IR machines. The customer gets the oxygen-free soldering environment practically for free. There will be no expensive investments for nitrogen tanks, supply lines, etc. The footprint of the vapour-phase soldering machines is very small. Because the heat radiation is low indirect costs e.g. climatic conditioners, etc., may be greatly reduced. Furthermore, due to the distinctly lower overhead to produce profiles and to control the production process the expenses for personnel are lower.
The machines may be very easily programmed and are changed-over in the briefest time possible to process another product, thus demonstrating their high flexibility.

4 Soldering Tips

4.1 Solder Defects

4.1.1 Solder Balls

The causes for solder balls are manifold:

- The temperature gradient in pre-heating is too high, which causes the solvent in the paste to evaporate violently, ripping out solder balls from the print of the paste.
- The paste print rests on the solder resist. (Wrong pressure or mask too large. Good results are obtained if the print of the paste is reduced by approx. 10 to 15 %).
- The applied solder paste is too old or of bad or unsuitable quality.
- The bottom side of the stencil or the screen is not clean, thus depositing paste residues on the assembly surface.
- Due to a bad wetting of the pad or component the wetting is incomplete. Some paste remains on the assembly in the form of balls.
- The amount of paste relative to the available pad size is too high.

Generally, due to the careful heating with vapour-phase soldering the solder ball formation is greatly reduced.

4.1.2 Wicking-Effect

The wicking effect is the rise of the molten solder on component leads. This disrupts the soldering to the contact pad below.
The wicking effect is known mostly with infrared or convection machines with very high pre-heating speeds. Lately it is found rather frequently with backpane SMD connectors, due to an extremely large amount of energy flowing across the pin-area into the metal. Thus the pins reach soldering temperature much faster than the pad below.

1. The wicking effect is mostly caused by bad solderability of the contact pads on the assembly.
2. The component leads reach the liquidus temperature much faster than the metallization of the substrate. This causes the paste to melt and to rise along the leads. In this case the so-called ‘top heat‘ is too high.

The formation of the wicking effect may be controlled via the machine technology by lowering the temperature gradient starting at approx. 150° C. With vapour-phase soldering the wicking effect is practically unknown, because of the negligible temperature differences on the printed circuit boards.

4.1.3 Tombstone-Effect

The tombstone effect occurs if - under certain circumstances during the reflowing process of the solder paste and its unilateral influence on the surface tension of the solder - the small bi-polar components start to lift (e.g. SMD condensators and resistors).
The most important reasons for the rising of the components are:

1. The layout of the printed circuit board does not, or only badly suits the component geometry.
2. The applied solder paste is bad or unsuitable.
3. The solder paste print is uneven and/or badly positioned.
4. The amount of solder paste is too high. (Optimum approx. 0,15 mm thickness of the mask and pressure reduction from 15 to 20 % with critical components of the size 08/05 and smaller).
5. The size of the stencil is not reduced. (Optimum 10 to 15% reduction).
6. The mounting displacement is too high.
7. The metallization of the components and the contact pad is insufficient.
8. The components have ‘balled‘ contact pads.
9. The solder resist is higher than the pad surface.

It sometimes happens – should the solder paste have not or only insufficiently dried - that the solvent evaporates violently during soldering. These small ‘explosions‘ may lift the components. However, this will not occur if the dwell-times are correctly set and suitable solder pastes are used.

But the most frequent reason for the lifting is an unsuitable pad geometry relative to its component geometry as well as too big a solder paste quantity.

1. The pads must not be too far apart - to prevent the surface tension of the solder to pull the component to one side. This will make it impossible to produce a solder contact on its other side, due to an insuffcient contact area. The pads may, however, be positioned only to a certain degree under the components as they must still produce a good solder contact (meniscus). The further the solder-joint lies below the component, the more difficult it is to check its quality subsequently.

2. A further rôle - when designing a pad geometry – is played by the metallizations of the solder areas on the components. Contrary to the SMD resistors, the SMD condensers possess metallizations along the sides and fronts. Due to the wetting forces additionally acting at these side areas, there is a certain compensation of the unilaterally lifting force on the front side. Thus, tombstoning does not affect the condensers as much as the resistors.

Regretfully, there are at rare occasions tombstones in assemblies which meet perfectly all the above conditions. The cause may be temperature differences within the printed circuit board. These temperature differences lead to an uneven reflowing of the two pad. Even if one pad is reflow-soldered only marginally earlier, the forces of the molten solder may pull the component into the vertical. Until now it has been generally recommended to improve pre-heating. Yet, this frequent advise to better pre-heating does not eliminate the temperature differences at the liquidus temperature. However, since the introduction of the variable temperature gradients in the vapour-phase process, these temperature differences are equalized in the simplest way. Reducing the temperature gradient approx. 30 K before reaching liquidus, will reduce the energy supply to the printed circuit. The intend is not to supply energy with the vapour, than to encourage heat conduction within the substrates and thus to equalize the temperature within the printed circuit board. This makes it possible to balance any temperature differences in the printed circuit board, and its components may be reflow-soldered homogeneously. Consequently, tombstones will not appear. This is the process, which ASSCON uses in all their standard machines for the last two years, and the process has stood the test extremely well.
A further possibility to reduce the tombstone effect is to use solder pastes with a low wetting potential. An elegant approach is also to use pastes which - instead of having an exactly defined melting point - feature a melting range of approx. 5 K.

4.1.4 Tombstoning comparing IR/Convection with/without N2/ Vapour-phase

A phenomenon often observed with tombstones is that they become more frequent the more the quality of the soldering atmosphere improves. Analyzing this failure behaviour of the assemblies in a typical production batch, the tombstone effect is unknown with IR soldering. However, with convection soldering with good N2 atmosphere it occurs quite frequently and in the vapour-phase machine most often.
As all parameters i.e. print, pastes, mounting, etc., of the respective assembly are the same there must be another reason.
The reason for this differing tombstone behaviour lies in the different degree of oxidation of the solder-joint when reaching the liquidus point of the paste. With reduced oxidation on the solder-joint, the wetting force increases in the meniscus. As the geometrical ratios in the solder-joint remain the same, a higher surface tension in the solder causes an increasing lifting moment and thus a tombstone.
This oxidation influence may be well observed in convection machines. Switching-off the nitrogen supply is a frequently used trick to eliminate tombstoning with known failure-prone assemblies. Without nitrogen the oxidition increases and consequently the surface tension – thus reducing the lifting moment.
Therefore, the paste volume must always be reduced to minimize the lever-effect in the solder-joint (responsible for the lifting- moment).

4.2 Assemblies mounted on both sides

There is no difference in the vapour-phase processing of assemblies mounted on both sides to that of the conventional soldering processes, i.e. radiation or convection.
Heavy components with unfavorable mass-solder-surface ratios have to be glued - if they are on the bottom side of the assembly.
This glue-process may be avoided, as long as sufficient attention is paid during the layout phase and all the heavy components are placed on the top side.
Generally, in the vapour-phase significantly heavier components stay in place without additional adhesive than in a convection process. Because in vapour-phase no oxidation occurs on the solder-joint and the surface tension of the solder is highest even very big components stay in place only held by the wetting force.
If heavy components must be glued, there are SMD adhesives, which cure at the process temperatures of the vapour-phase. This results in enormous savings as it does away with an additional adhesive curing process when soldering SMD‘s on both sides of an assembly.

4.3 Solder-paste selection

The melting point of the solder paste used should lie approx. 10 K below the boiling point temperature of the process medium.
When selecting solder pastes the mildest activated pastes, i.e. no-clean-pastes may be chosen due to the ideal soldering conditions (0 ppm oxygen). To minimize solder defects, pastes with low wetting force should be favored.
During practical application there seem to be – in spite of the same alloy combinations - distinct differences in the processing of these pastes. The characteristics of the solder pastes must be tested in each case relative to a smooth processing during screen printing and e.g. to the holding properties for the respective components.

4.4 Cleaning and cleanliness of the printed circuit board

Using the mildest activated or no-clean pastes the cleaning of the printed circuit boards is in most cases no longer necessary.

Certain products, e.g. those according to MIL or ESA specifications, electrically tested assemblies, etc., must be cleaned.

However, printed circuit boards soldered in a vapour-phase system may easily be cleaned off their flux residues with customary cleaning processes, as the flux residues are not burnt into the assembly and their chemical structure is not altered.

In future the cleanliness of the printed circuit boards after soldering will become more important. Particularly with edge connectors, LED´s, switches, potentiometers, any flux contaminations or outgassings from the printed circuit board will become more problematic and undesired.
Especially in these cases it is the vapour-phase process, which offers enormous advantages. In difference to the convection machines - in which the whole surface of the printed circuit board is always exposed to some contamination by the circulating air, the vapour-phase processes the boards in a very clean environment. The vapour-phase is actually a distillation column and thus always extremely clean - due its physical laws. Consequently and independently of the machine‘s contaminated condition, no foreign particles are deposed on the printed circuit boards during the condensation of the vapour,. Outgassings of the paste or of the printed circuit boards escape immediately from the vapour-zone, due to their lower specific gravity. Any solid matter which might accrue during the soldering process, e.g. solder balls, flux residues, will be transported into the sump of the machine where they will be filtered.
As no oxygen is present during the heating process, pastes with lowest and mild fluxing contents may be used. Consequently, the contamination of the solder pads by flux residues - after the solder-joints solidified - is minimal.

4.5 Curing of adhesives

Curing SMD adhesives in the vapour-phase is straight forward. Due to its careful and steady energy supply as well as its totally oxygen-free environment, the adhesive agents may be cured under the same conditions as solder pastes may be reflown.
This leads to the following advantages:

- Shorter dwell-times in the hot zones for curing, resulting in positive effects relative to the longevity of the respective components.
- Curing the adhesive and soldering the subsequent assembly bottom side is one process step. There is no other in-series curing process, thus saving costs.
- Bacause the adhesives are cured without oxygen no oxides will form on the printed circuit boards - which results in improved solderability.
- To cure the adhesive and to solder uses one profile only.

4.6 Lead-free soldering

With conventional soldering technologies there are substantial problems when using lead-free solder alloys in the production for lead-free SMD products. Although neither the handling nor the use of lead-free pastes is the actual problem. Any bad wetting behaviour may be counteracted by installing suitable inerted gas equipment and by using suitable fluxes. However, the components, potting compounds, printed circuit boards, plastics, etc., simply do not meet any more the required conditions for a lead-free soldering process. All boundary parameters are infringed upon, i.e. maximum temperature, time above liquidus, maximum dwell times in the oven, etc. With convection machines all the process limits have been reached. The air temperatures may not be increased further because this would exceed the maximum temperatures and the temperature differences on the printed circuit board. Neither may the machines be lengthened further as this would increase the times above liquidus and the maximum dwell times. Even an increase in the speed of the air-flow is out of question as this will displace the components.
Thus, in mass production one may be forced – if one maintains the present soldering technology, to tailor any critical materials to the process. However, from today’s view-point this results in enormous complications and overhead. Contrary to the costs of the pastes, which represent only a fraction of the costs of the assembly – a doubling of the costs of the components increases the actual production costs enormously. This, consequently, will create a substantial problem in earning capacity.

It is here where the vapour-phase - as the only soldering system - offers the inestimable advantage to continue using all hitherto known and processed materials. The costs of the machines are comparable and in some cases even lower than those of well known convection systems. Therefore, the vapour-phase offers enormous competitive advantages in the production of lead-free products.

Profile of paste containing lead. 200 °C end temperature
Profile of paste without lead. 230 °C end temperature

4.7 Void-free soldering

A critical property of solder-joints - from certain sizes onwards, is to form voids, which may lead to functional problems and questions as to their durability. E.g. the solder-joints of high-capacity processors may not dissipate their waste-heat correctly any more. Often only a fraction of the capacity of high capacity thyristors may be used. Yet, the trend continues towards even higher integrated circuits with power components on the printed circuit boards. All this requires to further reduce the formation of voids. The vapour-phase process offers inestimable possibilities to reduce drastically the formation of voids. Studies have verified that assemblies, which have been processed in a vapour-phase system produce only a fraction of voids -compared to infrared or convection processed boards.
The reason for the small amount of voids is the absolutely oxygen-free vapour-phase soldering process. As soon as there is an oxide film on the molten alloy, it is like a skin which inhibits the escape of the voids out of to the solder-joint.
This void behaviour is problematic and particularly so with lead-free soldering. Due to the bad wetting of the pastes the voids are not able to escape the soldering alloy. However, when soldering in a vapour-phase system the void behaviour corresponds to that of convection soldering with lead containing pastes. Generally, lead-free pastes are inclined to produce very high amounts of voids in standard convection machines.

4.8 Void-free soldering under vacuum cover

In spite of the extremely low amount of voids formed during the vapour-phase processing, still there are voids formed from a certain solder-joint size onwards. Particularly with power modules with solder-joints of several square centimeters, voids are very problematic. Due to the high production flows in these modules (several hundred ampères) - voids may lead to partial over-heating and thus to defects.

For these processes ASSCON Corp. developed a system, which uses the vapour-phase as optimal medium for the heating of even the heaviest products. This process produces a totally void-free solder-joint - by partially evacuating the solder product when it is still in liquid condition.

Such a soldering process with evacuation runs as follows:

1. Heating the solder product in the vapour-phase.
2. Conveying it from the vapour-phase in liquid condition to a partial vacuum cover.
3. Closing the vacuum cover.
4. Evacuating to approx. 50 bar.
5. Maintain vacuum for approx. 10 secs.
6. Ventilate cover with air or nitrogen.
7. Open cover.
8. Convey product to cooling zone.
9. End of process.

The whole process takes approx. 20 secs. longer. This system may be fully integrated in-line in its ultimate automation stage and may also be used in mass production. Even batch units may be retrofitted with such a vacuum system.

Void-free soldering of a power module under VP vacuum

4.9 Repairing assemblies

During soldering mistakes will happen. Particularly complex-shaped components such as multi-polar components, big BGA's, connectors, or components, which sit on printed circuit boards and require a high heating capacity, may only be de-soldered with great expense and low process reliability.
Here the vapour-phase technology offers a superb possibility. A small auxiliary system is used to de-solder such complex-shaped components - safely and without any damage. After re-constituting the solder-joint the respective components may be re-soldered. The quality of the solder-joint after the repair suffers only after approx. 4 to 5 repairs on the same assembly.
In many safety relevant applications the only permitted method of repair is with the vapour-phase.

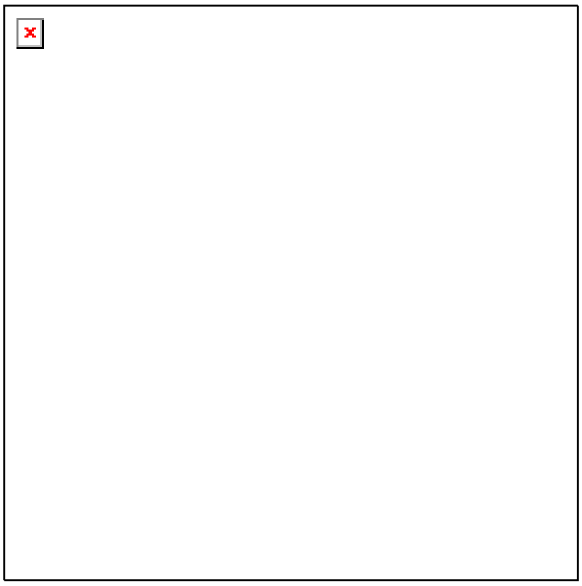
4.9.1 Repairing lead-free products

Due to the changed parameters for lead-free products, repair with conventional methods (hot air, solder bar, etc.) seem hardly possible any longer. Problems such a delamination, over-heating, oxidation, etc., negate highly qualitative repair work.
Thus, the vapour-phase is the only system, which makes repair possible - even with the most complex boards and components and without any negative effects.

5 Product spectrum that can be processed

Due to the high process reliability and the homogeneous transfer of the energy via vapour-condensation into the solder product, geometrical parameters, colour, packing densities, shape of the components, etc. do not affect the heating process.

Soldering a large area on aluminum oxide



The only important parameter, which is important for the soldering process is the temperature gradient wanted by the user. In the vapour-phase any desired gradient may be produced using the appropriate amount of vapour. Because the vapour condenses everywhere homogeneously and independently of the geometrical surface, one may even process three-dimensional printed circuit boards without any problem. In the vapour-phase even sensitive plastics may be processed without complications. Due to the good energy transfer property of vapour extreme masses may be processed as well. Backpanes with 50 layers and interior layers of large heat sinks as well as shields weighing over 10 kg may be soldered in-series.

6 Perspectives

6.1 The future of the vapour-phase soldering process

Due to the changes in the machine technology made during the last years, the disadvantages - relative to the conventional technologies of infrared and convection systems - have been eliminated. Because of its continuously superb soldering results the vapour-phase has re-established itself as an acknowledged production process.
The new component technologies and the new shapes of component packages will inevitably lead to an increasing use of the vapour-phase technology.
Another large field will become the lead-free soldering process. The damage potential in the vapour-phase soldering machines is very low and overheating is impossible. Thus, the pastes with higher liquidus-points may be used without problem in the lead-free soldering process. There is no need to change the printed circuit boards, components, etc.

6.2 New shapes of components

The physical lasws, which govern the vapour-phase soldering process make it possible to easily process the new shapes of the components as well as the mechanical parts as large area sockets and connectors. Already today the BGA´s, sockets, SMD connectors, etc., are mass-produced in vapour-phase soldering machines. The first trials for Flip Chips have been successful. Lead-free solders may be used without problem, particularly when soldering lead-free critical components in the vapour-phase.

6.3 Look-ahead towards the new machine technologies

Without any doubt, the trend is towards vapour-phase machines which may produce with the highest through-puts. For mass-production double- and triple-track machines are already available.
Of course, the further objective is to reduce the production costs of these machines even more.