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CFC free refrigerator technology / technologie de réfrigérateur sans CFC / FCKW freie Kühlschranktechnologie

GmbH

Transfair Engineering Survey:

Cooling Circuits Sealing:
- Brazing, Silver vs. Silver-free alloys with gas flux
- Lockring and
- Ultrasonic Welding
in the Household Refrigerator Industries Today

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Content

5. Sealing of Joints, Brazing and Filling Hole Closing

Circuit sealing, mainly brazing is still the **Achilles' heel** of household refrigerator industries. After-sales leak rates of 300 up to 1400 ppm in first 10 years of lifetime are far away of quality standards already reached in other field, like 4-4,5 σ (63-3,4 ppm).

HC-600a and HFC-134a Refrigerators - Requirements on Brazing. Sealing of energy saving CFC-free refrigerators require higher accuracy on materials, joint construction, brazing work and better control on used materials process and leak detection as needed in the past:

- The specification and control of brazing materials, flux, pipe construction and dimensions, pipe materials, their surface treatment, the content of oxide/oxidyl complexes inside the tube material, free of burrs and scratches, the cleanliness,
- The manufacturing process and control, burner flame or ultrasonic welding control, flux quantity,
- The entry control and quality control during operations,
- Last not least the way the joint are designed for optimal brazing, to reduce joints (7-10 joints without oil cooler, 9-12 with oil cooler, some models even with more joints) and to facilitate sealing operations, especially the spaces between pipe walls, tolerances of inner diameter of outer pipe and of outer diameter of inner pipe, and the overlapping area.

R600a has about 55% less charge quantity in weight than a refrigerator using R134a (or about 45% less charge than a refrigerator filled with R12). This much lower charge needs much lower acceptable leak rates (Σ0,5g/a) and higher quality in brazing joints. **R134a** is more aggressive to brazing materials as R12 or R600a.

Filling tube closing. If the R600a charging tube is good closed by a crimping tool to be applied twice per tube, perhaps by a pneumatically driven one, it is possible to use normal brazing to close the filling tube, but it is not recommended to do so. Today ultrasonic welding machines, like Stado's RSA3000-EX or a mechanical sealing system (like Lockring closing caps from Vulkan Lockring) are used because of the inflammability of R600a. Ultrasonic systems are expensive in investment, but save so much in process, that the machine often amortises inside of 1 year (see details at end of this chapter).

Since long Germans have fixed standards for brazing materials, fluxes and processing DIN 8505/8511/8513, used all over the world, which meanwhile were transferred into EN 1044/1045 standards, slightly modified to reflect new technical requirements.

How to braze correctly, which alloy and which flux has to be used and how to work is described in the following (see for joint designs also Transfair Engineering: Designing and Prototyping of Refrigerator and Freezer Cooling Circuits, Düsseldorf 2006):

5.1. Brazing of Tubes in the Refrigerator Circuit

Correct closing of the refrigerant circuit is the most relevant part of the refrigerator quality. Leaks, especially ones not detected during manufacturing, can cause high repair costs in the factory, after-sales and loss in reputation. Also blockages of capillary cause by wrong brazing. Today joints in household refrigerators must allow leak rate underneath 1g per year for R134a and underneath 0,5g per year for R600a and material should not enter into the cooling circuit and must be resistant against refrigerant. Brazing is used in majority of joints in a refrigerator circuit and therefore we should take a closer look on this process and the relevant factors, which decide about the quality of brazing joints.

Brazing material is wetting the surface of not melted basic materials (steel, copper, aluminium, etc.) to be joint, only possible if

- basic material surfaces are **blank metal** (free of oxides and oil)**,**
- **the basic metals and brazing alloy had reached working temperatures** and if
- minimum **one brazing material component can build an alloy with the metals** to join.

The most relevant factors for brazing quality are the following:

5.1.1. Free of Oil and Grease

The joints to be brazed must be **free of oil and grease.**

Specification for the Supplier: The supplier of circuit element to be brazed must guarantee and verify that the tubes to be brazed are cleaned from oil and grease.

Visual Entry Control on Compressors Tubes: tube ends to be brazed have to be free of oil. The problem in this point is the oil filled compressor transported on difficult roads, so that entry **controls** are needed and if oily, the joint end must be cleaned before brazing. High energy efficient compressors has high oil levels and tilting of compressor or refrigerator with already mounted, but not yet brazed compressor causes oiled joints!

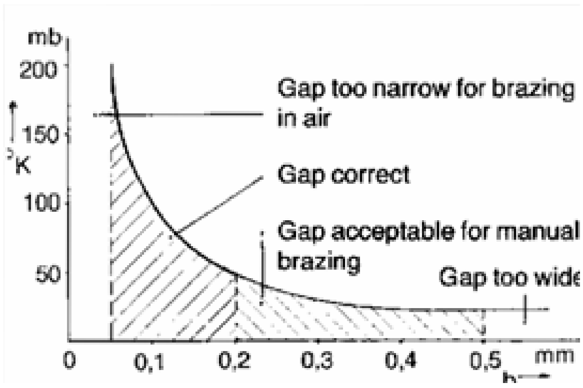
Manufacturing Instructions and Controls for Reworks: after running of the refrigerator joints are often oily which must be removed.

Degreasing: by ultrasonic or degreasing materials, like Acetone (pay attention: Chlorine Carbon connections often used as degreasing materials are often dangerous for workers and environment and should be avoided or only applicable with special precautions!). If the brazing joints are not free of oil or grease they have to be cleaned. All joints to be reworked after running of the system must be cleaned from flux, eventually oil, if compressor had run, and brazing alloys.

5.1.2. Gap of the Joints

Capillary attraction (p_k in mbar) is used to fill the gap with brazing materials. Under atmospheric pressure a gap between 0.05 and 0.2 mm should be maintained:
By **material specification** (inner-, outer diameter and wall thickness tolerances) and **entry control** (measuring of samples of boxes per batch) this factor can be kept under control. In addition the **person in charge of flux application and tube joint assembly as well as the welder should keep the gap visually under control** to ensure that the material can enter. A Pk value of 100mbar means 1m h increase of column of water. The joint surfaces should be parallel and not conical (max. 2-5°).

P_k



5.1.3. Overlapping Length

Popular misconception is that increasing overlapping length would increase joint strength. The contrary is often the case.

The **optimal overlapping length of inner and outer tubes should be in the range of 3 up to 6 times of the least tube wall thickness**: in case of copper tubes an optimal value is in the range of 3 times of wall thickness while in case of steel 4-6 times. The overlapping in our applications is normally in the range of 5 mm, from which about 4 mm is used for brazing and the rest to reduce attacks from the refrigerant to the material. Higher overlapping reduces the strength by increasing the flux inclusions and bond defects that must be avoided. In addition higher overlapping is wasting of materials.

The best is to make the parts self-jigging to facilitate to achieve ideal heat pattern.

The person in charge should keep the overlapping length under control for the assembly of tube joints and the welder.

5.1.4. Flux and Filler Brazing Alloys

Relevant for the correct selection of filler alloy and flux is:

- The liquidus temperature of alloy, and hence the lower work temperature (best is < 700°C),
- the melting range (difference between liquidus and solidus temperature), to reduce the tendency to form fillets, a smaller range is favoured,
- fluidity, and hence the distance of molten alloy flowing through the joint,
- the tendency to liquidation, the first part to melt is richer in silver, zinc and - if inside the alloy – Cadmium, while the solid part contains more copper, which requires higher temperature on the remaining part to melt.

In our application following joints are used to be brazed:

a) Copper-Copper tube joints
b) Steel-steel tube or copper-steel tube joints

5.1.4.1. Brazing Alloys for Copper-Copper Tube Joints

Material Specifications. For these joint **no flux** are needed and 2 different so called **Copper phosphorus alloys** can be used acc. to EN1044 or DIN 8513 Standards:

EN1044	DIN8513	Composition	Sample material	Melting range	Work Temp.	Commend
CP203	L-CuP6	93,8% Cu/6.2% P	BrezeTec Silfos 94	710-890°C	760°C	Without silver the cheapest
CP105	L-AG2P	2%Ag/91,8% Cu/6.3% P	BrezeTec Silfos 2	645-825°C	740°C	Better, easier to work, but €7,60..19/kg more expensive
CP104	L-AG5P	5%Ag/89% Cu/6% P	BrezeTec Silfos 2	645-815°C	710°C	

1) Degussa had sold 2000 their Brazing portfolio to Emicore BrezeTec ®

2-5% silver inside copper phosphorous alloys facilitate work and reduce failure rates, but increase costs by about €7,60 (2%Ag) respective €19 (5%Ag). Such alloys contains already Phosphorus as "flux"; it oxidized by air oxygen to Phosphorpentaoxid, which reacts with copperoxidul to coppermetaphosphat. Such joints are not difficult to perform if the surfaces to join are clean. Relevant is that the melted alloy **will always flow towards the hottest part of a joint even against the force of gravity**. Therefore the flame position and direction is relevant. See picture in Para 5.1.5. Burner and flame. Much more difficult are the following joint:

5.1.4.2. Brazing Alloys for Steel-Steel tube or Copper-Steel Tube Joints

To braze joints between 2 steel tubes or between copper and steel tube expensive Silver-Copper-Zinc brazing alloys containing 24-30% Silver and flux are useful and mainly applied. There exist 3 brazing alloy families:

- Ag-Cu-Zn without Cadmium and tin (Ag 5-50%, working temperature 725-870°C)
- Ag-Cu-Zn-Cd with Cadmium, but without Sn (Ag 20-50%, working temperature 610-750°C)
- Ag-Cu-Zn-Sn without Cadmium (Ag 25-56%, working temperature 650-750°C)

Alloy with higher tin (Sn) content is not recommended for our application because the tin-iron bridge phase causes problems.

The higher silver content is selected to reduce working temperature underneath 700°C. By this way the heating up time can be reduced by 40-50% while other metals, which can reduce melting temperature, can cause joint brittle (Cd, Sn, Al, Mg) or hot-shot (Pb, Bi, Sb), when added even in small amounts. But such silver alloys are costly.

Standard materials are:

EN1044	DIN8513	Composition	Sample material	Melting range	Work Temp.	Commend
AG204	L-AG30	30%Ag/38%Cu/32%Zn	BrezeTec 3075	680-810°C	750°C	Expensive, less reworks and long lasting
AG306	L-AG30Cd	30%Ag/28%Cu/21%Zn/21%**Cd**	BrezeTec 3003	600-690°C	680°C	Much easier to apply,but Cadmium is poisoning

Technically alloys containing Cadmium, like the AG206 are the best, easier to apply with less reworks and less quality problems. But Cadmium as CdO_2 vapour causes cancer. A special precaution with correct working exhausts and filters is a must; still we do not recommend using these materials. Their use is restriced in many countries, like in EU **(**RoSH/2002/95/EC) to 0.01% or 100 ppm by weight of homogeneous material. 1g AG306 on a 2kg piece is already exceeding the limit. The AG204 is Cadmium free.

Standard material can cause so called liquid **metal inbrittlement** (it makes the joint brittle and porous) **on Zn-galvanized steel tubes as used**, which can cause fractures and leak channels under stress and tension, for example during refrigerator transportation. Therefore we recommend special brazing alloy with lower silver content containing Silicon, Nickel and Mangan, for overlapping tube joints of galvanized steel tube as used on cooling circuits, which prevents these kinds of leaks:

ISO3677	Composition	Sample material	Melting range	Work Temp.	Commend
B-Cu37ZnAg MnNi630/800	24,5%Ag/37,2%Cu/33,5%Zn/2%Ni/2%Mn/<0,3 %Si; max.%: Al 001/Bi 0,03/P 0,008/Pb 0,025	BrezeTec 2577 or Comet 2577U	630-800°C	770°C	Compromise of costs and quality, long lasting

The version Comet 2577U is already covered with Flux (FH10 acc. to EN1045).

These silver alloys are technically best and under conditions of calculating service costs and reputation damages even cost wise a **good brazing solution for refrigerator circuit joints made of zinc coated steel tubes**. It reduces cost on reworks, is easier to handle, tolerate more operators' failures and last not least reduce leak failure rates on long lasting household refrigerators and damage on trade mark reputation.

Price wise these silver alloys cannot compete with silver-free alloys (see next paragraph). Has it subsequent costs in **reworks, service** and on **brand reputation? How relevant is this durable good reputation criteria? And how much a slightly better, but more expensive product can realize higher prices?** Not easy to answer!

Silver free cheap brazing alloys. From time to time some refrigerator manufacturers used **cheap Silver free Cu-Zn alloys** (Cu 58-66%, Zn 30-40%, Mn 0,8-2,5% an Si 0,1-0,2%,) **in combination with gas flux in this tube joints to cut drastically the costs:**

EN1044	Composition	Sample material	Melting range	Work Temp.	Commend
CU306	59%Cu/Rest Zn/ 0,8% Mn, 0,8% Sn	AV Salvature SM23 MR	880-900°C	950°C	Cheapest kind of material to be used with gas flux (Linde-Flux, AV Salv. L89N or 88), often without FH20 or FH21 paste (AV salv. D54 or BrazeTec rs). Problematic is Tin (Sn) content. Overheating during delicate work process can cause porosity and imbrittlement. Gas flux has limits to remove oxides 4mm inside 0.05-0.2 mm gap.
CU303	59%Cu/Rest Zn/0,15% Mn, 0,1% Sn	BrazeTec 60/40	870-900°C	900°C	

See also technical considerations to gas flux in chapter c) Flux. Take a look on cost savings:

5.1.4.3. Total savings on silver free alloys versus sales price and brand reputation

Brazing technology for steel tubes	Material costs About 5-6 joints/refr.		Δ Work + Rework	Δ Service costs	Total costs savings of manufacture	Higher sales price /refrigerator as result of brand reputation	
	Costs/joint	Cost/refr.				Δ Price	Overall Δ
30% Ag brazing	€ 0,115	€ 0,575…0,70					
Silver free brazing	€ 0,015	€ 0,075…0,09					
Differences	-€ 0,10	- € 0,50…0,61	+€ 0,01.0,3	+€ 0,02..0,05	- € 0,15..0,58	+ € 0,50..5,00 ?	+ € 0,35..4,42

Base of calculation:
- **Silver price:** €360-400/kg, 25-30% Ag alloys compared with silver free alloys.
- **Work/Reworks:** Δ Failure rate: 0,1-03% Ag alloy -> 0,2-0,3% Ag-free alloy
  + nearly negligible more work time and more energy costs.
- **Service work:** Δ **Service r**ate 0,04-0,15% -> +0,05-0,2% **,** ~ 40% compressor repair €100

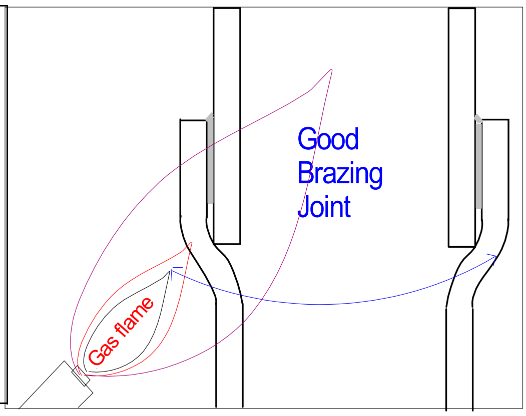
Savings on materials per fridge-freezer are with €0,50-0,60 very high! Even if we deduct the increased reworks as result of this technology inside the factory and extra service costs, which was strong fluctuating in the considered cases, it is still €0,15 up to €0,57/refrigerator and economically such silver free brazing technology really sounds. But pay attention: **leak tightness on durable goods, like refrigerator is one of the most relevant criteria of a brand** for most customers and if a well reputed brand can realize a price €0,50 higher than other cheap brands, than there is no benefits anymore in this silver free brazing technology. But for companies without such brand reputation, which allowing them to reach better pricing, silver is simply cost and less profit.

At least this was the consideration of some refrigerator manufacturers. After facing **increased return of already delivered refrigerators, sealed with silver free alloys, manufacturers went back to above mentioned silver brazing materials.** 1993 Electrolux had introduced in all their refrigerator factories these silver free alloys in combination with Gas flux. 2005 Electrolux returned back to Silver alloys to improve refrigerator quality and to reduce reworks in their factories to 0,1-0,3% and cut the significantly increased failure rates in after-sales service and to avoid reputation damages on such durable good with nearly no service inside 15 years lifetime.

Such failure rates are top secret in our branch, so others cannot learn from it and have to make own experience. 2002/3 Whirlpool in Italy started the same experiment to use silver free alloys to reduce costs; other followed, but if it will have effect on their brand reputation, probably will return to traditional methods to keep reputation or regain markets. The problem is that some failures occur only after long time of use.

5.1.4.4. Tube brazing quality criterion

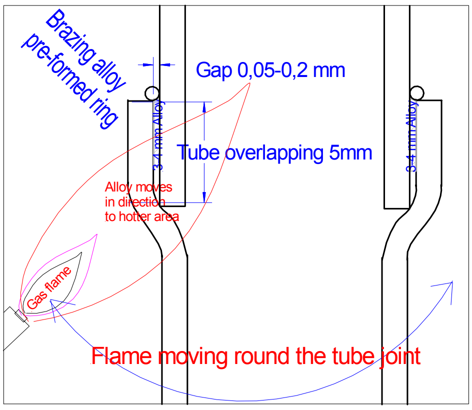
Relevant is that **3-4 mm of the overlapping area is first removed from metal oxides** and **completely filled with alloy**. **An external fillet is only wasted material** and does not mean a good joint though quality inspectors often like it. Such fillets are a result of wrong heat distribution (see burner and flame direction) or bad selected alloy and flux. To fill completely the overlapping gap with alloy **the tube sections must be hotter than the rod**! Otherwise we get only a nice fillet, which under stress and over time can break easily, the joint will leak. With silver free brazing alloys and gas flux it is not easy to reach such a quality criterion. The failure rates increases.



Furthermore we recommend using **compressors with copper coated steel tube ends** easier to braze as the ones without such coating. But copper coated steel tubes have to be treated in brazing as steel tubes, not copper tube joints.

Aluminium coating or Aluminium-Zinc coating on steel tubes (as used for refrigerator evaporators) must be completely removed on the joint areas because the aluminium will prevent correct brazing!

In case of tube-to-tube joint of dissimilar parent materials: the component with greater coefficient of expansion should be normally on the outer position. That means copper tube should be normally around a steel tube and not opposite. But we neglect this rule in the charging tube. Following increase of length by heating to 700°C exists: Brass 1.9%, stainless steel 1.6%, Copper 1.1%, steel ST37 1%, mild steel 0.8%



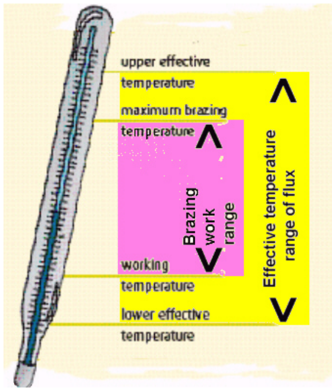
De-burred "Broken corners" at the beginning and end of a capillary path will enhance filling of the joint. At least burrs must be removed. Never incorporate a grove midway through a joint (unless used for placing a brazing alloy ring to be heated).

Pre-Formed Filler. Often in developing countries this expensive material are wasted. More alloys do really not increase the quality of the joint. One possibility to reduce consumption is to use pre-formed filler alloy rings positioned in the right way. The rings are more expensive than rods, but make sure that only the needed quantity is applied to fill the 360° of tube joining area.
In automated process is used.

5.1.4.5. Flux paste, powder and gas flux

Flux is always used - with exception of copper joints, if phosphorous copper alloys are used,

- to **remove oxide coating** from surface of the tubes to be joint, from brazing alloy,
- to **avoid any new oxidation** during the heat process, and
- to **reduce surface tension** of the molten alloy so that it can spread out uniformly.



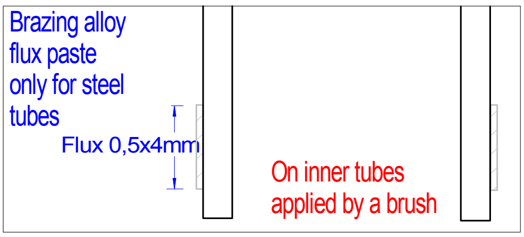
A flux can do this only if it has

a) a **high rate of oxide solving and oxide reduction capability**,
b) a **melting point at least 50°C lower than the brazing alloy** and that it is at this temperature up to max. brazing temperature fully effective (see picture on right side, and that
c) it can **form fast a cohesive and uniform coating** which remains intact at the required brazing temperature during the brazing time. The viscosity at the required temperature (for example 650-750°C for Ag-alloys or 750-950 for Ag-free alloys) must be high.

Fluxes applicable for the brazing with Silver-Copper-Zinc alloys are the type FH10 acc. to EN1045 (previously F-SH 1 acc. to DIN 8511) with operation temperatures of 550-800°C used for Silver alloys. For silver-free alloys a flux FH21 or FH20 with a temperature range of 750-1000°C is recommended.

Oxide coating on surfaces of bright metals are normally about 30-50nm (10^{-6} mm) thick. To dissolve these oxide coatings we need a layer of a very effective flux, like BrazeTec h flux, of 0.02 mm thickness to joint 2 overlapping steel tubes using silver alloys. Max. 5 weight % of flux can be solved on such metal oxides. Therefore the gap should not be less than 0.05mm (a gap of 0,02 in not enough), if lower melting point brazing alloys for overlapping tubes are applied.

The thicker the oxide layer on the tube is the more flux is required and the wider the gap is needed. But too much is also not useful for the cooling circuit, so that these metal oxides on tubes should be avoided by entry controls and controls on storage time. No one has time removed it mechanically. This could be done in service.

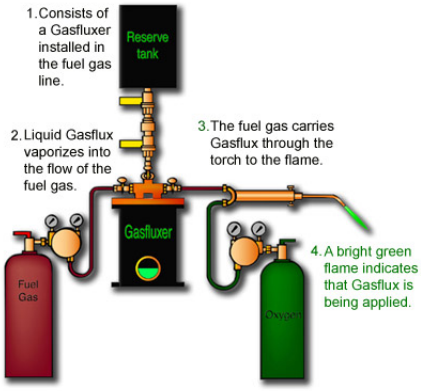


To joint **overlapping** steel tubes the simplest and safe solution is the application of a flux paste in the correct temperature ranges FH10 for Silver alloys or FH20 or FH21 for silver free alloys. With a small brush (4mm width) the paste can be painted around the outer surface of the inner tube with a layer of about 0.5-1 mm thickness, at least 0.2 mm layer. This should be done at the position on the assembly line in which the tubes were assembled and not at the brazing position.

Flux powder can be used only on the position of brazing, but to apply the correct quantity with powder is more difficult.

FH10 (H-paste) for silver alloy is water based boric compound with fluoride. If it becomes too dry for the application by brush water can be added and the paste can be stirred. Excess of such flux needs to be removed after brazing by water or pickling agent.

The Brazing Process Time is Relevant: To permit the flux to perform min. 3-5 s of flux in liquid stage are required, normally 5-10 s are used. After 4 minutes (including heating up time) flux loose their function. This normally happens with low heat Propane/Butane flame without oxygen (Bunsen) so that the heating up time is too slow (so called "**torturing**"). Even adding of new flux will not help. The flux must be removed first with pickling agent (BrazeTec Flux-Ex).

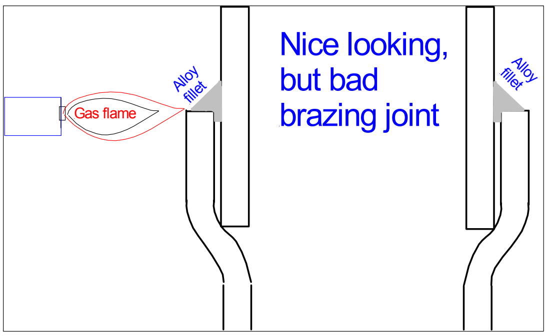


Gas Flux. Steel furniture industries use gas flux (Lindeflux, AV Salvature Ecoflux) instead of paste or powder flux with success for V-joints, but these joints must not be leak tight. We meanwhile get even leak tight joints with gas flux on such V-joints or geometries similar to V-joints which we use on some few cooling circuit elements, but we still face problems if such a technology is used on tube overlapping joints (see picture on last page) mainly used in the refrigerator industries, if no other flux was added: some **bad mechanical joints** are already identified during production by **tube stress tests with 20-30 bar** (applicable only without Aluminium parts use in the circuit), which is often part of a Helium leak test, but not even all bad joints can be eliminated by this method; worse are the increase of failures after delivery of the refrigerator and loss of trade mark reputation, if the refrigerator fails inside the first 10-15 years. **The reason is that the gas flux cannot enter in the extend (4mm), concentration and time as needed in a tube to tube gap of 0,05-0,2mm and remain 5-10s,** even if flame gas pressure is directed to gap – against in next chapter mentioned flame direction to use capillary effect. For these reason a paste or powder flux is still recommended to use in addition to the gas, which are not used to do yet. This probably could increase the lifetime of these joints significantly. Gas flux strongly prolongate the effective time of paste flux. Therefore it is recommended to use.

- Gas flux cannot remove the oxidised steel surface inside such a small gap in the extend and times needed and it has lower surface tension reduction as needed to get the melted alloy inside the gap (3-4mm), so it remains mainly as fillet outside the overlapping area. If cheap alloys with a higher melting temperature (>870°C) are used, the last effect is even worse.
- The thermal fusion of liquid brazing alloy to the Zink coated steel surface, treated only with gas flux is lower, so that during long time under temperature fluctuation and vibration the refrigerator can leak. The leak rate increase was significant for Electrolux to return to previous more expensive joints.

But these 2 problems could be reduced by adding paste flux. How much it will reduce failure rates on long term use of refrigerators we can't say yet. There are no data yet collected. There exist only data for silver-free alloy and gas flux without other fluxes.

- If low melting silver alloys (610-750°C) are used in combination with gas flux we face another problem: The effective temperature of such gas flux is often above 800°C and therefore above the melting point of the alloy, which would be overheated so that low-boiling constituents of these alloys will evaporate before the flux can be fully efficient. So the effective temperature range of gas flux is relevant, if it is added.



Typical for such an application is the nice **fillet** above the tube gap - quality inspectors like it, as they can see the seal -, while a correct sealing of overlapping tubes with low quantity of alloy can only be inspected by destroying the joint or X-ray. Such a bad fillet seals the tube joints, but can break under stress and on longer time.

Flux coated brazing rods. Alternatively to the a.m. paste flux there exist also rods with a flux surface, like BrezeTec Comet 2577U. The advantage is that one rod only has to be handled and not additional paste and brush or powder. It reduces work operation time if it is correct made. The disadvantage is that it needs more experience to cover all joint surfaces with flux, and that it has higher leak failure rates. It is easier and less failing if flux paste is applied by a brush during tube assembly. To avoid the rate of reworks the paste flux applied by brush during assembly of tube joints seems still the safer solution, not only in developing countries and areas with workers with lower brazing experience and less discipline.

Residual hydroscopic flux like FH10, FH11 and FH12), containing bor compound with fluoride, must be removed by water or mechanically with a brush after cooling down to avoid corrosion, while FH20 flux bor compound without fluoride has not to be removed.

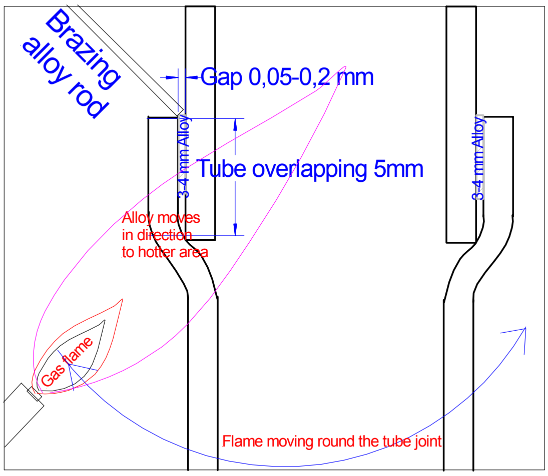
5.1.4.6. Aluminium-Aluminium joints

Such joints can be brazed with filler material AL104 acc. to EN1044 (DIN8513: L-AlSi12) containing 88% Aluminium and 12% Silicium. The eutectic between Al and Si is at 577°C with 12,6% Si content. Brazing alloy, like BrazeTec L88/12 as rod or as preformed ring with FH10 flux (F30/70) or FH20 (F32/80) or as brazing paste already mixed with flux (BrazeTec P20/45) are used. But **pay attention**: The brazing alloy melting point is not far away from the one of Aluminium with 660°C max. (often used Aluminium alloy AA1070 at 655°C) so the process window is small. Therefore Argon arc welding (with AC-high frequency) is often a better alternative.

5.1.4.7. Copper -Aluminium tube joints

We regular use aluminium evaporators in the refrigerator industries, which must be connected to steel tubes, bridged by copper tubes to avoid difficult steel-aluminium joints. Flame brazing aluminium to copper is possible, but difficult. The eutectic between Cu and Al is at 548 °C. When the flux melts and the surface oxides are removed, inter-diffusion of Al and Cu is so rapid at braze temperature, that the Al and Cu materials are quickly consumed to form the eutectic metal. No filler metal is needed; it is created in-situ. The brazing time is short and temperature is critical to minimize the inter-diffusion and metal consumption. The only requirement is that the design of the joint allows metal consumption without sacrificing joint integrity. Therefore we do not recommend flame brazing of copper-aluminium joints, but special electric welding machines, like magnetic pulse welding. Also Lockring systems are usable, but per joint even more expensive as purchased joints already made with such machines.

5.1.5. Burners, Gases and Flame Direction



The development of the correct heat pattern is very relevant for the quality of the brazing joint. The first objective being to insure that **all parts of the joint obtain a temperature that is at least equal to the work temperature of the chosen filler alloy** (770°C in case of BrazeTec 2577). The second objective is to ensure that the **location of the filler material to be melted is the last place of joint to achieve brazing temperature.**

That means the heat should be applied always from the direction the filler brazing material has to flow, because **molten brazing material will always flow towards the hottest part of a joint even against the force of gravity**. The zone in which the brazing material has to flow should be hotter than the area where the rod is positioned, which should be on the coldest point. To heat up the rod by direct flame does not make any sense.

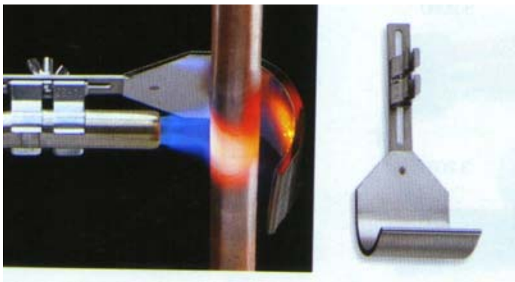
The problem is that a flame (especially if Oxygen is added) surely will more rapidly heat up exterior surfaces as interior joints. To reach a more balance heat pattern the parent metal must have time to conduct the heat away from the flame application points to the interior parts. It should neither be **over-heated** which would cause

- boiling of brazing filler material,
- decomposition of flux and flux contracting to islands or
- even melting of the parent material

nor **under-heated** so that the melted filler will stop flowing.

Burner Gases	Flame temperatures	For work temperatures
Propane entrained air	1750°C	700-850°C
Natural gas entrained air	2000°C	700-950°C
Acetylene-compressed air	2600°C	800-1150°C
Natural gas - Oxygen	2850°C	800-1250°C
Propane - Oxygen	2850°C	850-1250°C
Hydrogen - Oxygen	2950°C	950-1300°C
Acetylene - Oxygen	3200°C	950-1350°C

Burner gases. Their selection depends on work temperatures of used brazing alloys (see table on right side) and cycle times. Often hot **acetylene-oxygen flames** (flame temperature: 3200°C; work temperature: 1250°C) are uses in industrial brazing processes for speed reasons. This is not wrong for careful welders. But in this case we have to focus the control on **over-heating problem**, which can be seen in small **craters caused by bubbles,** if the burner flame is not moved around the tube. The hotter the material the more of this craters can be seen. The 'orange peel effect' is a sign of over-heating, which should be avoided. Bubbles in this case are also enclosed in the joint and can cause leaks. Tubes, specially the capillary tube can melt and block. Another sign of over-heating is white or yellow-brown deposits near the brazing point caused by Zinc oxide (white) or Cadmium oxide (yellow-brown). The welder should always keep under control that he will not overheat the flux, brazing filler material or tubes. Propane without Oxygen is in risk to be too slow, which can cause torturing (too long heating, so that flux is destroyed), anyhow not hot enough for silver free alloys. To add compressed air to burning gas is technically good, but needs more time as Oxygen. Propane/Butane with Oxygen is often used as compromise between speed and quality.



To facilitate a more homogeneous heat pattern, to speed up the brazing process, to avoid bad bonds, enclosures of flux and micro channels an Inox reflector or even a **twin head or** ring burner could be use. But it strongly depends on welder's skill and favours.

In a good joint the 4 mm of overlapping zone of about 5 mm with a gap on 0.05-0.2mm is completely filled with alloy and neither a crater /orange peel nor a fillet is seen on the surface, nor became the tubes melted. But this not regular reached today, in some factories even an exception.

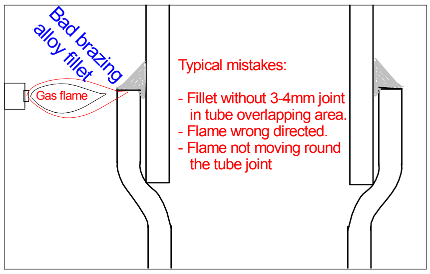
5.1.6. Reworks of Joint

Reworks should be avoided at all as it is not easy to do, because before joints with leaks can be reworked the flux (with pickling agent) and filler material and - if existing - the oil must be removed completely. Re-heating of leak joints with flux and rods as often done can not remove brittle areas as result of over-heating or too long heating and cannot make sure that areas without filler will be refilled.

5.1.7. Observations in Production and Recommendations

Switching over from lower sensitive Halogen (5g/year) to more sensitive mass spectrometric leak detection surely increases the detected leak rates, if same level of performance in brazing is kept. The level has to be improved to reduce expensive service cases in the field as it often needs replacement of compressor running overheated by low level of refrigerant. Even reworks in the factory are difficult and disturb the production flow. Some mistakes can only be detected and strongly reduced, if a stress test on tubes (not possible with Aluminium roll bond) with 20-30 bar is made, but not completely, so the brazing process must be strictly kept under control.

Following **typical mistakes** were often reasons for leaks and reworks - beside of the above mentioned ones:



a) **Un-experienced welder or young men welder** often are not able to work over a long time this quite boring work in same quality and with same concentration as needed to get good results.

b) **Silver brazing alloys wasting fillets.** Wasting of expensive silver alloy brazing material is very frequent. Also silver-free alloy fillets are often covering only bad joints. More used material is not improving joints but normally a sign of bad work, beside of high costs, if silver was used. Controllers often believe, that the excess (fillet above the joint) show a good work, but it's the contrary, specially if filler is not 3-4 mm inside the gap around the tubes, regular caused by next mistake:

c) **The flame is directed to the rod** instead on tube area, to which the alloy should flow; heating the rod goes faster, but achieves very bad quality joints.

d) **The heating time was too long** (**torturing**), the flame and its area of tube touching not hot enough, so that the flux has lost effect.

e) **Fluctuation of heat applied to different tube zones.** Often the heat are not equally distributed over the complete tube joint, the flame was not coming from the area to which the alloy should flow, one side was completely overheated (brittle), while the other side not enough heated so that the alloy did not really enter in this gap part of cold tube areas in the extend needed (3-4mm). An Inox reflector or a twin flame burner allows often a more homogeneous heat pattern in high speed production as a single flame burner. But twin or ring burner use needs experience, and there exist good welders who can use better a single flame burner.

f) **Silver alloy selection.** Standard silver alloys with 30% or more silver content are often used. Cheaper and for the application even better are material like BrazeTec 2577 with only 24-25% Ag (see a.m. specification) but Mangan, silicon and Nickel to prevent brittle areas cracking under stress or tension.

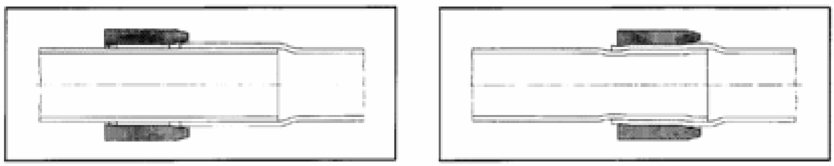
g) **Silver free alloys with gas flux.** If no other flux was applied the brazing material inside gap are not in touch with blank metal, but its oxides, al least in the deeper areas. Also failure described in e) as result of higher work temperature can be regular watched.

h) Flux. Flux is often wasted and wrong applied. Excess has bad influence of cooling capacity and can block capillary tube. Liquid flux in a bottle to be inserted in the gas flow of the burner in addition to paste or powder it is improving and allow longer period of flux reactivity. Flux reaction temperature must be lower than the melting point of brazing alloy. Flux coated rods are more difficult to apply. Also after brazing hydroscopic bor flux, containing fluorides has to be removed completely; otherwise it is a spot for oxidation.

i) Copper coated compressor tubes. All good compressor suppliers supply copper coated compressor tubes which are much easier to braze.

5.1.8. Lockring Tube Joint

Before mounting After mounting



There exist rings to joint 2 tubes by a Lockring by a hydraulic tool. Beside of costs for hydraulic unit with tool (€ 6000, - with flaring tool for copper or aluminium tubes, not for steel tubes, further € 1750,- is needed. But the mayor costs are the Lockring itself for € 0,12 plus Lockprep liquid € 0,005 so that a joint would cost in the range of € 0,125. If it is a steel-steel joint than it would be cheaper than a brazed joint using expensive silver alloy with high silver content, if it is a copper joint, it would be more expensive than brazing with low silver or no silver alloy. In addition the tube diameters must be quite exact and the minimum wall thickness of copper tubes is 1 mm.

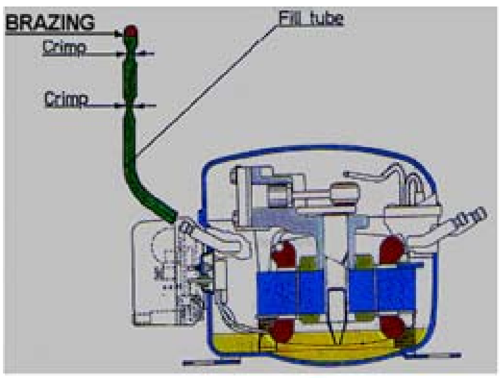
Only in few joints (Aluminium-Copper), also few capillary tube joints are still worth to be used. In other cases it is too expensive.

5.2. Closing of the Refrigerator Filling Tube

There exist **3 methods** to close the filling tube:

- Soldering or brazing after crimping with a mechanical or pneumatic pinch-off pliers (in case of HC-600a crimping must be applied 2 times for safety, but in case of HFC-134a crimping should be applied 2 times to prevent cooling agent from softening it again),
- Closing by a Lockring cap or
- Ultrasonic welding

5.2.1. Closing the Filling Tube by Brazing or Soldering



Previous closing of filling tube: Brazing alloy or Lockring cap. First the copper filling tube has to be at least once (HFC-134a) or twice (HC-600a) crimped by **pneumatic pinch-off pliers and brazed.**

The failure rate (leak rate) is in the range of 0,13-0,28%.

The use of brazing on R600a refrigerators has an explosion risk by wrong application and therefore it is normally not used in the production. The details of brazing were described in the last chapter.

5.2.2. Lockring Stopper Closing System

There exists a special pneumatic tool to close the filling tube with a cap:

The pneumatic tool costs only € 1600, but the Lockring closing cap in large-scale purchase € 0.13 plus about € 0.005 for Lock prep liquid. **The failure rate of such a system is in the range of 0.17-0.25 %.**

Lockprep glue Lockring stopper Crimping and assembly jaws

Crimping

First the pneumatic tool is crimping the tool, then some glue is applied to tube end and the stopper on the tube positioned on tube end by turning. Afterwards the tool is placed on the Lockring stopper to seal the tube. By opening of the sliding valve the Lockring is pressed over the collar of the stopper and the tube end is sealed.

5.2.3. Ultrasonic Welding of the Refrigerant Filling Hole

The use of brazing, soldering or Lockring for sealing of the copper filler tube has a number of disadvantages for the manufacturers in comparison to ultrasonic welding such as:

a) **Leak rate:** The refrigeration manufacturers using ultrasonic welding have reported that the use of ultrasonic welding in comparison to brazing and Lockring cap closing has resulted in a significant reduction of the amount of leakage taking place. This is only valid, if all 3 alternative processes were well set up in production, because in some few cases, the ultrasonic welding failed, because of wrong set up of the new process (selected parameters of machine and copper tube specification);

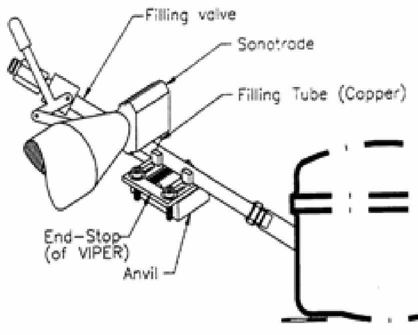
b) **Less works and work costs:** The use of solder or brazing solutions require extra handling, higher work costs and more time. To enable one to braze after the filler tube has been filled, the filler valve has to be removed. This valve can only be removed once the same has been tightened twice with a wrench to prevent the cooling agent from softening again. This method according to our experience has an extra time demand of 14-19 s per cooling system. The ultrasonic welding with 6 s is the fastest method of filling hole closing, normally done either by the operator of the refrigerant charging board or by the operator of leak detector to control closing.

c) Higher leak failure rates on brazing or soldering and Lockring cap closing causes much more **repair works** and involved costs in comparison to ultrasonic closing of filling tube; repair of an already filled R600a refrigerators is very time consuming, 1-2 g of refrigerant can remain inside compressor oil so that it can cause a **quality reduction** on the repaired refrigerator. Using ultrasonic welding the manufacturer depend less on the working skill of the operators and repair men in comparison to brazing or soldering.

d) **Health problem and hazard risk:** The use of brazing is not environmental friendly, because of the gases given off during the brazing operation (Cadmium etc.). Closing filling tube of already charged HC-600a systems by brazing or soldering has also a hazard risk of explosion, which could be avoided by ultrasonic welding.

e) **Costs for material, operation and investment amortisation:** The ultrasonic welding needs **very high investment.** A valid cost comparison must include this high amortisation cost of ultrasonic welding and surprisingly the costs per filling tube closing are the lowest using ultrasonic welding in comparison to other methods. The main factor is not the lower work costs, but the refunding on the **copper tube recycling** (see chapter "Cost comparison and amortisation" and comparison table underneath). In one step the ultrasonic machine close the tube and cut about 1/3 of the cupper filling tube, so that cut piece of the filling tube are returned to the cupper tube supplier for recycling of this cupper, which is without any contamination by soldering or brazing materials.

5.2.3.1. Ultrasonic tube sealing machines on the world market



Stapla Viper. Till end of 2001 the leading manufacturer in the field of Ultrasonic welding of copper tube closing was **Stapla**. 1998 they developed an ultrasonic welding machine called Viper, which was very successful on the market. Their competitor at this time was **Amtech** with the model called **Ultraseal,** though much cheaper sold (often -40%), customers often bought it only once and went back to soldering or brazing because of high failure rates of the Amtech machine and its problems in control and adjustment, or customers replaced it by a better machine. Because of higher leak rate Amtech was not successful in this field of filling hole closing. Therefore Stapla gained about 80% of the world market in copper tube closing of refrigerator with the Viper till 2001.

The Viper machine - though highly reliable in sealing of tubes and very successful - had some disadvantages, which causes Stapla to develop a new model called Cobra upon demand of customers in 1998:

- the diameter of Viper head (Converter, Booster and Sonotrode) and cylinder was quite low, so that only soft copper tubes with less than 1 mm wall thickness (normally 0,7 mm) and quite limited copper quality tolerances could be welded and closed by ultrasonic; and even slight compressed air tolerances could cause leaks;
- the cycle times should not be too fast to avoid exhausting of the machine, and the production load per machine should not be too high; in high capacity lines and in 2 shift operations the Viper reaches their borders.

Stapla Cobra. But the problems for Stapla started by introducing their new, stronger Cobra model in 2000: Several household manufacturing customers, used to get reliable machines from Stapla, forced Stapla to take the Cobra back. Stapla lost end of 2001 their leadership in tube sealing equipment and their very high reputation producing reliable ultrasonic welding machines for copper tubes.

Commercially the problem became severe because meanwhile Stapla received the first time a technically strong competition and last not least, the leak rate level, which could be reached by such equipment, became significantly lower:

STADO RSA-3000. In the past Stado has produced one version of the Viper for Stapla and the welding tools, so Stado got some years of experience, before the 2 companies split their co-operation and Stado went with their own new developed model on the market. Leading engineers and maintenance men went from Stapla to Stado.

STADO RSA-3000-Ex

5.2.3.2. Comparison tests of refrigerator manufacturers

In 2001 and 2002 Stado started to sell their machines in Europe and competition between Stapla and Stado could be mainly gained in Europe by STADO in new sales after machines were systematically tested. In May 2002 Electrolux/Zanussi (Sussegana), the main refrigerator factory of Electrolux in Europe, had invited Stapla and Stado to run their machines under severe production conditions (Line 8 with different models on same line) before ordering new machines. According to the internal report of Electrolux/Zanussi the Stapla Cobra causes too high failure rates during production and the Zanussi operators had problems to handle the heavy Sonotrode part of the Stapla Cobra machine, while the Stado machine runs perfectly under the high production capacity of the Sussegana factory. Therefore Stapla lost the business, like before at Whirlpool Casinetta, the main factory of Whirlpool in Europe. Stado also gained in Whirlpool (Siena/Italy), Electrolux (Spain), Electrolux/Vestfrost (Denmark), Electrolux Lehel (Hungary) and at other refrigerator producers. In some factories, Merloni in Naples/Italy; smaller Zanussi factory in Scandicci/Italy, Candy (Italy), Stapla could gain. In Korea (Samsung, Lucky Goldstar) Stapla was forced to take back 18 Cobra machines. Stado gained inside of 2 years making such machines 70% of the European market of tube sealing machines.

Such competition is good for refrigerator manufacturers: it will force both machine manufacturers to increase their technical performance and development efforts and limits costs. We recommend executing such comparison tests on machines of different manufacturers from time to time to check which machine is best.

Important for the weld quality and lifetime of Sonotrode (=costs of weld) is

- to avoid too high power on the Sonotrode as really needed which reduces the quantity of welds per Sonotrode,

- to use not hard copper tubes, but clean soft copper tubes (see underneath the specification) and
- to avoid 2 different copper tube wall thicknesses without switching the machine program between the different welds.

The tubes can also harden by overheating during the brazing on the compressor steel tube. Meanwhile Stado clients make welds above 30000- 35000 per Sonotrode, to go even much higher as it is possible on a Stado RSA-3000, it is not recommended as this can increase the leak rates.

5.2.3.3. Safety

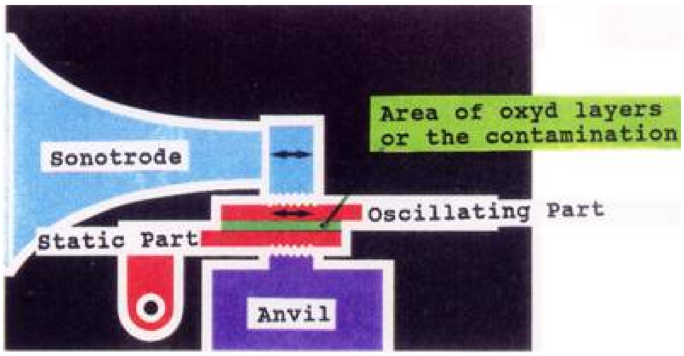
Safety. Stapla and Stado ultrasonic tube sealers have been designed for 2-handed operation for safety reasons to fulfil well established machine safety standards. Both companies have developed EX-versions for their machines (Stado RSA-3000-EX, Stapla Cobra EX), specifically for closing of cooling systems using ISOBUTAN and PROPAN cooling agents in accordance with European standards and standards in other areas. In case of R600a refrigerators only such ultrasonic welding machines should be used. The old Viper does not exist in Ex-version and are legally not allowed to be used in Ex-zones.

5.2.3.4. What is Ultrasonic High Frequency Welding?

The process belongs to the friction welding, but in cold phase, that means the metal is not melted and no high temperatures are reached during welding. This is relevant if we have to close a filling tube of a compressor filled with Isobutane with an ignition temperature of 460°C. The welding pieces are rubbed to each other under pressure by high frequency vibration; this will clean the metallic surface on the joints and whirl the molecules into each other to a fix and long lasting joint.

An ultrasonic welding machine of Stapla and Stado consists of following modules:

- **Ultrasonic high frequency generator** up to 3000V and 20000Hz piloted by a Performance module which measures the mechanical pressure on the high performance swinging system to adapt needed frequency accordingly, the generator is equipped with automatic frequency control, overload and quality control system which indicates by an acoustical and visual alarm any failure, electronic timers in real time without delays, end pulse device to reach longer life-time for tools and digital switches to set process times;



- **Pneumatic control** to control the mechanical pressure on the welding zone;

- **The high performance swinging system** to pass over the needed high frequency surface friction between the 2 copper tube inner surfaces to weld together **consists** of the converter to convert electric high frequency energy into mechanical energy with Piezo ceramics, the booster to increase amplitude and the Sonotrode to get in touch with the tube as well as some mechanical components for fixing the swinging system; without tool change the same Sonotrode and anvil can be used to close compressor filling tubes mounted on right or on left side of the compressor; it is also used to close the tube on the filter, if cooling system was evacuated from 2 sides (see Transfair Engineering: Evacuation);

- Furthermore the control unit consists of **process timer controls** to control movements during welding;

- **Welding tools.** The system is equipped with a long life **Sonotrode** and **Anvil to be used for welding and cutting.**

5.2.3.5. Quality

In general relevant for the quality of ultrasonic welding is that the following parameters are measured and kept under control:

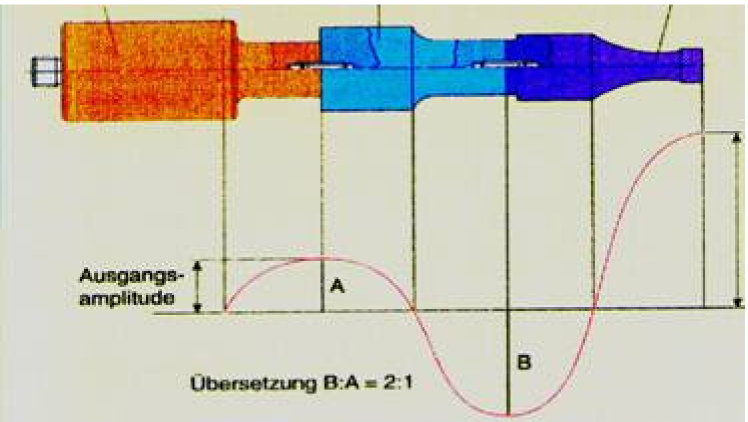
On the machine side:

- **Welding pressure** between Sonotrode and anvil permanently measured and kept constant;
- **Welding time**, normally calculated by Microprocessor according to other process parameters or constant, by varying other parameters accordingly;
- **Frequency**, fixed according to machine mechanical parameters;
- **Amplitude**, the length of the swinging of the “stand still” wave, will be kept constant during welding;

On the copper tube side:

- Same copper tube diameter and wall thickness during same programme (or 2nd programme for other dimension must be called on machine),
- Same copper quality and hardness (see specification) during same programme,
- Avoiding of overheating along full length of tube during brazing of copper tube to compressor steel tube which can cause tube hardening and oil vapour on inside tube wall, and no tilting of compressor, so that welding point remain oil free.

Stado Converter **Booster** **Sonotrode**



Starting amplitude **Standing wave** **Final Amplitude**

Normally the same soft-heated copper tubes with an outer diameter of 6 mm and an overall length of 130 mm are used in the refrigeration industry - see attached sketches. We prescribe the same tube length, however in the case of ultrasonic welding the **portion of the tube, which is recovered, is free from impurities** normally associated with brazing or soldering. The reason for all European refrigeration manufacturers having a minimum filler tube length of 130 mm / 150 mm is to ensure that during the welding the compressor oil in the compressor through heating does not build up a soot layer in the tube at the site of the weld. This soot if present clings to the welding site on the inside of the copper filler tube and under pressure during welding causes leakage to occur.

Nevertheless also the a.m. reliable ultrasonic welding machines Stado RSA-3000 and Stapla Viper must work under controlled conditions to work reliable which are the following:

- only copper tubes of good quality (see specification underneath) can be used and the quality of this tubes must be kept, in case of Stapla Viper 0.75mm wall thickness, for Stado 1 mm wall thickness is no problem, but for a 0.75 mm tube the lifetime of the Sonotrode is often longer and
- the welder, who brazes the copper tube filling hole on the compressor should work correctly, if he overheat the tube so that oil vapour will be laying on the inner surface to be welded later by ultrasonic, such machine - like closing by brazing - will face problems.
- Also the mechanical parts, distance of Sonotrode to anvil must be regularly calibrated by special guides, which must be part of the supply to ensure correct pressure.

Nearly all refrigerator producers in developed countries make ultrasonic welding of the filling hole because it is **very reliable** and strongly **reducing the material costs**. Such ultrasonic welding machines are very expensive (the system price is €25.000, but by selecting the good models such systems are **very reliable:** A good trained worker needs less reworks (see table underneath). **Such investment also amortise fast (see next chapter)**. It is the fastest. It closes and cut copper tube excess in one operation. And last not least it is the most reliable method (if the correct machines are selected, the machine correct set and the quality of copper tube under control). Some manufacturers even do not leak check the system after closing with ultrasonic welding anymore, but we do not recommend it, as it needs good experience in calibration of the ultrasonic welding machine and control on the used copper tube being free from oxygen (oxidyl complexes).

No silver alloy is needed; the copper tube wall can be thinner. In case of Stapla Viper it must be thinner 0.75 mm instead of 1mm, while Stado RSA 3000 can work with even 1 mm wall thickness. Also the needed copper tube length is reduced and a part of tube can be recycled.

Copper tube specification (relevant for welding quality and lifetime of Sonotrode):

Oxygen free copper tubes for ultrasonic welding. Bosch specification are according to DIN 17 671 plus additional requirement marked with *

Standard:	DIN 17 671
Name :	SF-Cu F22, F22

Material No.	2.0090.10
Formula	Cu 15 b 18 rr.R
Chemical content in %:	Cu min 99.90 %; P 0.015 - 0.040 % (acc. to DIN 1787)
Electrical conductivity (at 20°C)	40-50 m/Ohm mm²
Density	8.9 g/cm³
Strength Tube acc. to DIN 17671:	- Till 3mm wall thickness: 220-270 N/mm² drawing strength; Cracking extension A5 40% min, hardness 55 HB - above 3mm wall thickness: 200-260 N/mm² drawing strength; Cracking extension A5 40% min, hardness 55 HB - Drawn, soft heated, in tube with measure tolerance acc. to DIN 1754, straight or in rings of min. 700mm inner diameter, end of drawn tube removed, on to ends gas tight closed.
Surface:	Clean, without any surface failures, inside must be blank, free of oxide and of humidity.
Inside:	No oxidyl complexes in the walls

5.2.4. Criteria of the selection of tube sealing technology

5.2.4.1. Reliability of process

First criterion for the selection of the ultrasonic welding units is the reliability of the filling hole closing process to seal the tube: in other words the leak rate. Which leak rate can or must be accepted? Leading refrigerator producers want the lowest technical possible leak rate, which was

- in the past with 0,1-0,15% reachable by good companies in brazing and by Stapla Viper for 6*0,70mm soft copper tubes normally used; but
- by good manufacturers on a technical level of <0.06%, reachable by Stado RSA-3000 EX at comparison time August 2003. If this technical level can be reached meanwhile also by other machines must be tested again, we have no actual data.

Customers satisfied with Stapla Cobra, like Zanussi in Scandicci (the main factory of Electrolux in Sussegana has purchased after tests the Stado machines), or Merloni Naples consider leak rates of 0.15% as ‘excellent’.
Why the criterion ‘lowest technically possible leak rate’ is so relevant? The reason is the high costs and time consumption of repairs and the quality reduction of repaired refrigerators, especially of the ones already filled with Isobutane. The Stado welding machines reliability in terms of leak rate (measured in factories equipped with Stado and Stapla machines) were the highest, which means with the lowest leak rates on ultrasonic welded tubes. By introduction of this process the failure rate starts often at 0.6% and inside of 2 months goes down to <0,1% - in good companies with high quality control even to 0.016% - after well establishing the process using soft 6x0.70mm copper tubes. Using tube quality with fluctuating hardness or dimensions without changing the process parameters easily increases leak rates by factor 10 up to 100. See comparison table on next page. For further Criteria see next chapter.

5.2.4.2. Cost Comparison and Amortisation of Investment

Second criterion is the process cost, the material and work cost, in case of ultrasonic welding the quantities of welds to be made by a set of Sonotrodes and anvils as consumables, which mainly decide on costs per tube closing. Ultrasonic welding can and should be done with thinner tubes 0.70 mm, which is cheaper, while the alternative method needs at least 1mm wall thickness. The processes of brazing and of Lockring as well as the materials are described in the last 2 chapters. In the table underneath only the costs are mentioned. The equivalent of ‘material’ costs of ultrasonic welding is the quantity of welds, which can be done per tool set consisting of sonotrode and anvil. It should exceed 20000 welding of copper tubes 6x0,70 mm if the tubes are according to the extended DIN 17671 standard as requested by Bosch-Siemens Hausgeräte (see specification in last chapter) and if the machine is correctly adjusted to the tubes to be welded which must be the same or a second program has to be called to weld a different tube. Customers using the Stapla Viper come to 17000-25000 welds per Sonotrode, the Stapla Viper has only 1 working area; while customers using the STADO RSA-3000-EX with 2 working areas makes per Sonotrode today 35000-70000 welds. The Stapla Cobra is fluctuating in this point and far away from such results of above 35000 welds on a 6x0,7mm copper tube with low leak rates. The tool costs (sonotrode and anvil) are on the same price level of about € 700. If bigger sizes of tubes or harder copper are used, the power must be increased and the lifetime of sonotrode reduces. For costs per tube sealing of a refrigerator see comparison table underneath. The work time needed for the sealing processes are very different. The table contain a range of work costs, because of the high differences in the world. In low wages countries the cost differences between the 3 processes are lower, but still significant. As result of differences in leak rates and wages the work intensive repair costs differs, so that a cost range are mentioned in this table.

5.2.4.3. Investment costs

Third criterion is the cost for the machine. In the past the prices of Stado RSA-3000-EX and Stapla Viper and later Cobra were similar (€25000). A big mistake would be, to consider this criterion independently from the other cost factors. It should be integrated in the cost analysis per produced piece as **amortisation costs,** an important amount especially for the higher investment needed for ultrasonic welding in comparison to the other technical solutions to seal tubes. The amount per refrigerator depends – beside of the yearly capacity - on the interest rate to be paid for a credit or received for investment or at a bank (present value calculation), in this table we calculate with the range of 5-10%. Countries with higher nominal interests' rates often have high inflation, which should be deducted from the nominal value, so that it normally would not exceed the 10 % rate.

STAPLA Viper in the past still today and the Stado RSA-3000-EX ultrasonic welding equipment has been successfully used in the refrigeration industry, not only in Europe, but worldwide. Manufacturers, who use R134a or Isobutane cooling agent in the compressor of the refrigeration and freezer unit, normally employ the use of brazing, the Lockring method or this ultrasonic welding for sealing the copper filler tube. **Data taken from several refrigerator producers, who all previously used the brazing or Lockring method, has resulted to following cost comparison table with the mentioned data ranges:**

5.2.4.4. Process cost comparison and investment amortisation

a) Comparison Table: Tube Sealing of Filling Tube and Filter Tube (2 Side Evacuations)

Tube Sealing of Filling tube and Filter tube *(2 side evacuation)*	**BRAZING/ SOLDERING**	**LOCKRING**	**ULTRASONIC STADO RS3000**
High Reliability: Low leak rate [%] measured after established process in many factories 0)	0,13-0,28%	0,17-0,25%	0,025-0,1%
Process costs per system closing (2 tubes per system):	Without copper tube costs, but including cost cuttings on thinner tubes and tube recycling in case of ultrasonic welding		
-Copper tube cost reduction for thinner tube 1) less 4.45g per tube at copper cost of € 1,45/kg	130*6x1mm=17.8g -0	130*6x1mm=17.8g -0	30*6x0.70mm=13,35g - 2*€ 0,03=- € 0.06
+ Materials	Alloy, Gas, flux: 2x € 0,035=€ 0,07	Lockring cap €0,13 Lockprep €0,005 2x € 0.135= € 0.27	Sonotrode+Anvil €700:52500 welds=€0,013 2x € 0,013= € 0,026 +Energy: € 0.0008 2)
+ Works on 2 tubes per system (including removal of filling valve, handling), **work cost** calculated with €3,20-30/hour 3)	22-27 s € 0.02 … 0.225	17-22 s € 0.02 … 0.18	7-9 s € 0.008 … 0.075
+ Repair as result of leaks (materials/work/equip-ment amortisation): €410/per repaired refrigerator 4)	0,13..0,28%*€4..10 = € 0,005…0,028	0,17..0,25%*€4..10 = € 0,007… 0,025	0,025..0,1%*€4..10 = € 0,001...0,01
Service and maintenance costs of equipment/ piece	€ 0,001-0,002	€ 0,007-0,014	€ 0,016-0,03
+ Amortisation (10 years) put on process cost - capacity of 100000/year/machine 5) - capacity of 200000/year/machine	5% rate…10%rate € 0.0019…0.0024 € 0,0010…0,0012	5% rate..10% rate € 0.0026…0.0032 € 0,0013…0,0016	5% rate…10% rate € 0.0339…0.0427 € 0,0170…0,0213
- Copper recycling € 1.00-1.40 per kg for clean, not contaminated copper 6)	0	0	40*6*0.7mm=4,4g - 2* € 0.005= - € 0,01
Total process costs **- without machine amortisation:** **- with machine amortisation:**	 **€ 0,10…0,33** **€ 0,10…0,33**	 **€ 0.30…0.49** **€ 0.31…0.49**	 **€ -0.02 …0.07** 7) **€ -0.001…0.11** 8)

Remarks to the table: Tube Sealing of Filling Tube and Filter Tube (2 Side Evacuation):

0) Real leak rates are slightly higher than measured ones, because the applied leak detection methods including mass spectro-metric ones are strongly disturbed from background signals from similar materials (foam blowing agents), but the ratio between the methods of nearly 10 times less leaks on ultrasonic sealed joints in comparison to the others remains in this scale.

1) The wall thickness for the filling tube using Lockring or brazing is 1mm while the wall thickness of this tube using ultrasonic welding is only 0,75 mm. That is for a 6mm outer diameter tube of normally 130 mm length

   Volume*spec.weight=weight

   Volume of 1mm thick tubes: $V=(D^2-d^2)*/4*L=(6^2-4^2)*\pi/4*130mm=2042mm^3=0.002dm^3$ |*8,9=17,8g

   Volume of 0,70 mm thick tubes: $V=(D^2-d^2)*/4*L=(6^2-4{,}6^2)*\pi/4*130mm=1515mm^3=0.0015dm^3$ |*8,9=13,35g

   By taking into account the specific weight of Copper of 8,9kg/dm³ the difference is **17,8g-13,35g= 4,45g copper per filling tube as result of different wall thickness**. With a copper price on such tubes of € 1,45/kg: the cost of the 17,8g copper tube for brazing and for Lockring is € 0.12 while the thinner tube for Ultrasonic welding with 13,35g cost at moment € 0,09, so that by using the ultrasonic welding tube cost reduction of € 0.03 per tube and on 2 tubes € 0.06 will be saved in comparison to brazing and Lockring. Copper prices are fluctuating, but %-wise the difference remains.

2) Ultrasonic welding generator has 3kW and uses about 45% of it during 0.6s plus low stand-by power: € 0.0008 per refrigerator (2 welds)

3) The work cost are not only the wages, it contain all costs of work including continuation of payment during holidays, illness, meetings, social security, benefits, wasted or idle times and excess of workers. In high efficient factories the used of equipment goes up to 79%, in lower efficient companies utilisation is more in the level of 58%. Time of stops of lines because of break-down of a foaming or else, power failure, missing parts, have to be added to the effected work cost also that in many developing countries the staff is 2-3 times higher than needed to execute production according to measured work process times. If someone pay a worker only € 160/month (12 months), with a.m. social costs +70%, a line efficiency of 58% +42%, double staff as needed +100%, the costs ends up to €3/hour for the effective executed work. Therefore we only can enter here a very high range of work costs/hour and the figure has to be adjusted to local conditions.

4) Average repair cost per leaking refrigerator is fluctuating mainly because of time intensive work and work cost, but also the works are different because of different set points on quality to be reached.

5)

Workplace costs:	**Amortisation /10 years**	**Equipment costs on piece with**		**5% yearly rate**	**10% yearly rate**
		100000 unit/year	**200000 units/year**	**100000-200000**	**100000-200000**
Brazing: € 1500	€ 150	€ 0.0015	€ 0,0007	€ 0.0019-0,0010	€ 0.0024-0,0012
Lockring € 2000	€ 200	€ 0.002	€ 0,001	€ 0.0026-0,0013	€ 0.0032-0,0016
Ultrasonic € 26500	€2650	€ 0.0265	€ 0,01325	€ 0.0339-0,0170	€ 0.0427-0,0213

   But for investment we have to spend today, but get returns the next 10 years; therefore we should not add on the pieces the invested amount divided by the manufactured pieces, we have to apply for comparison reason between technologies of low and high investment a rate between 5 -10%/year on investment cost similar to a present value calculation. This would increase the amortisation costs over years by 28% up to 61%, which makes the piece made on expensive machine proportionally more expensive as when it is made with cheap investment. It is like if you invest the amount on another place and want such a yearly return rate on investment. But the rate height and even the difference in the investment amount because irrelevant, because of the very fast cost saving of Ultrasonic welding in comparison to brazing and the Lockring system. See next table Amortisation of investment of ultrasonic welding in comparison to alternative processes.

6) The ultrasonic welding close the tube and cut the tube excess of copper tube of about 40mm, which are recycled:

   Volume of 0,70 mm thick tubes: $V=(D^2-d^2)*/4*L=(6^2-4{,}6^2)*\pi/4*40mm=4662mm^3=0.0004662dm^3$ |*8,9=4,15g

   Taking into account € 1.00-1.40 per kg recycled copper which makes a further saving of € 0,004-0,006=€0.005 +/-20% per joint using ultrasonic welding.

7) The 2 copper tubes to be sealed are not considered as part of process costs. The ultrasonic welding allows thinner cupper tubes than the alternative processes and furthermore to recycle a part of the tube, so this savings are applied to this process. Therefore the process cost can be negative, if the leak rate is low and the rate for investment only 5%. If the leak rate is going to the upper range and/or the interest rate is higher than 5%, the process cost more than it saves, but ultrasonic welding is with distances the cheapest with very low leak rates.

8) Because of the very fast amortisation of the investment in the average inside of 1.3 year +1 /- 0,5 out of savings on materials, work and copper recycling for 100000 refrigerators per line or half for 200000 refrigerators per line, there is no much sense to add the machine cost on each produced piece and to add interest rates as normally done, which is obvious by studying the next table.

b) Table: Amortisation of investment of ultrasonic welding in comparison to alternative processes

Process cost difference of Ultrasonic Welding	Minimum	Average	Maximum
- to Brazing without amortisation costs	€ 0.12	€ 0,19	€ 0,26
- to Lockring without amortisation costs	€ 0.32	€ 0.37	€ 0.42
Amortisation of investment difference after production of			
- in comparison to Brazing Δ € 25000/ (€ 0.12…0.26)=	208333 refrig.	131579 refrig.	96153 refrig.
- in comparison to Lockring Δ € 24500/ (€ 0.32…0.42)=	76563 refrig.	66216 refrig.	58333 refrig.

Such tables are quite general and cannot reflect different cost conditions of each refrigerator producer. Therefore Transfair has developed an **MS-Excel ® file (trade mark of Microsoft)** to enter individual cost conditions with different tube sizes and geometries, different work costs etc. **to allow in each single case to calculate amortisation of ultrasonic welding investment.** Such Excel-file can be granted upon request.

c) Conclusion

A refrigerator factory with 100000 refrigerator production on one sealing line per year needs in the average 1,3 year to amortise the high ultrasonic investment in comparison to brazing (Δ € 25000) and 8 months in comparison to Lockring (Δ € 24500). A refrigerator factory with 200000 refrigerator production on one sealing line per year needs only 8 months (in comparison to brazing) respective 4 months (in comparison to Lockring). Out of the savings in materials, work and recycling of not contaminated copper (see Comparison Table: Tube Sealing) the refrigerator factories, which purchased this technology, had practically paid the higher investment for the ultrasonic welding.

In countries with low wages, but excellent work quality, (= low leak rates on brazing or soldering), the amortisation time would increase to 2 years and 1 month, the same amortisation time would be reach in the average if only 50000 refrigerators are produced per year on such a line instead of 100000 per year.

In high wages countries with low leak rates factories in practice amortise such an ultrasonic welding line of 100000 units per year inside of 1 year, when switching from brazing, on a line with 200000 units per year inside of 6 months. Factories in such countries which replaced their Lockring lines by ultrasonic welding reached the amortisation on a 100000 units/year line already after 7.6 months.

The above tables with ranges of data allow companies interested in the ultrasonic welding technology to calculate their speed of amortisation by using their own figures according to their individual conditions.

5.2.4.5. Service of equipment

Last not least the fourth criterion is the service. The supplier of ultrasonic welding must have a good and fast reacting service, first to set of the system in the factory with a good training, to supply fast the sonotrode and anvil, which are consumables, and to support the client if he face problems with this high tech machine in short time. Without such a service such equipment is just waste of money and cannot be operated with needed efficiency concerning leak rate and % of use in production.