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Efficient Tube Welding with Hot Air – Best Practice

EXPERTISE | Reliable Plastic Tube Welding with Hot Air



Authors
Markus Lipp, Head of Business Development
Pius Enz, Head of Business Line Process Heat

Management Summary

Initial Situation

The cosmetics, pharmaceutical and food industries rely on plastic tubes for packaging. At the same time, the demand for environmentally friendly and recyclable materials is growing. This is why more and more monomaterial plastics are being developed and used to manufacture monomaterial tubes or coated cardboard tubes. Despite these new and more sustainable materials, tubes need to offer sufficient protection and durability for the product held within. The material price should also be under control. In addition, tubes made of new materials should perform in the same way as standard plastic tubes during processing, filling and welding.

Aims

Manufacturers of tube filling and welding machines use a range of technologies to seal and weld filled tubes. Each process comes with its own pros and cons depending on tube material, machine capacity and machine design.

Filling and welding machine operators require a welding process which offers process reliability, achieves consistent high weld seam quality and corresponds to machine capacity. Purchase and operating costs of filling and welding machines should also be kept under control. To reach these objectives, machine operators need to select the machine design which is right for them.

Analysis and Practical Test

This expertise compares different materials and manufacturing processes for plastic tubes. The most commonly used processes for welding tubes were compared. This confirmed that machine capacity plays a key role when it comes to selecting the suitable welding process. Other important aspects are investment and operating costs. Hot air is often used for tube welding. The research looked into the technical limits of this process and the types of material which can be welded with hot air. It also examined whether and how energy consumption was higher than other technologies and if the resulting higher operating costs could be reduced.

Recommendations

Welding plastic tubes with hot air works equally well with all common tube materials, produces a high quality welding line and enables greater process reliability in operation. Hot air welding is ideal for new and sustainable materials such as coated cardboard or bioplastics because other technologies do not work with the same process reliability. In the meantime, technologies have become available to operate air heaters efficiently and with minimum resources. Here, hot air recirculation plays a key role in keeping operating costs down and using the machine sustainably.

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1. Introduction

In the cosmetics, pharmaceutical and food industries, manufacturers are facing the challenge of welding and sealing tubes in a sustainable and energy-efficient way after filling. At the same time, they are increasingly turning to new sustainable tube materials (e. g. cardboard tubes).

This white paper therefore addresses following question: How do you weld plastic tubes or plastic-coated cardboard tubes after filling reliably, efficiently and with minimum resources using hot air?

For this, we compare the various processes which are currently in use. We focus on welding with hot air, because this process is most commonly used. The reason for this is obvious: Welding tubes with hot air is quick and easy. However, this technology is currently still more expensive in operation for end customers, compared to other processes.

Delimitation: Manufacturing empty tubes (tube blanks) also includes welding processes. These are not the main focus of this expertise because the priority lies exclusively on tube welding.

For added clarity, we generally use the term plastic tubes. This refers to all plastic-coated tubes (including cardboard tubes and tubes made of alternative materials).

Sealing tubes with hot air is always a welding process, which is why we always use the term welding tubes in this context (instead of sealing).

2. Tube Market Overview

Plastic tubes are everywhere. For hygiene and care products, for example: Toothpaste, shower gels, shaving and skin cream, hair gel, hand cream etc.

For a range of tasks in the trades and industry, plastic tubes ensure that substances are protected for longer and remain usable, e. g. glue, sealants, grease, dyes etc.

Pharmaceutical products including lotions, eye drops and sun cream are filled in plastic tubes and remain sealed durably and safely. Veterinary medicine requires disposable tubes, e. g. eyedrops for dogs and cats, which are also filled in tubes.

Plastic tubes are also increasingly found in the food industry. Sauces, spicy pastes like wasabi, ketchup, mayonnaise, vinegar and dressings, chocolate cream and peanut butter are also available in practical plastic tubes.

The plastic tube packaging market in 2020 was estimated at USD 10.72 billion and is set to grow to USD 15.39 billion by 2026. This includes a forecasted annual growth rate (CAGR) of 6.3 % between 2021–2026. *(cf. MordorIntelligence, n.d.)*

Plastic tubes are one of the most popular packaging formats in the personal hygiene sector of the cosmetics and hygiene industry. This is mainly due to the fact that they are easy to use and carry, and offer flexible storage and dispensing options for a range of products.

Plastics also meet the requirements of various industry sectors, offering low manufacturing costs, low weight, flexibility and durability. In addition, plastics used for tube manufacturing are also odor and taste-neutral and look great, with a variety of design options.

As hygiene and personal comfort becomes increasingly important worldwide, the demand for plastic tubes is growing in the cosmetics industry, in particular.

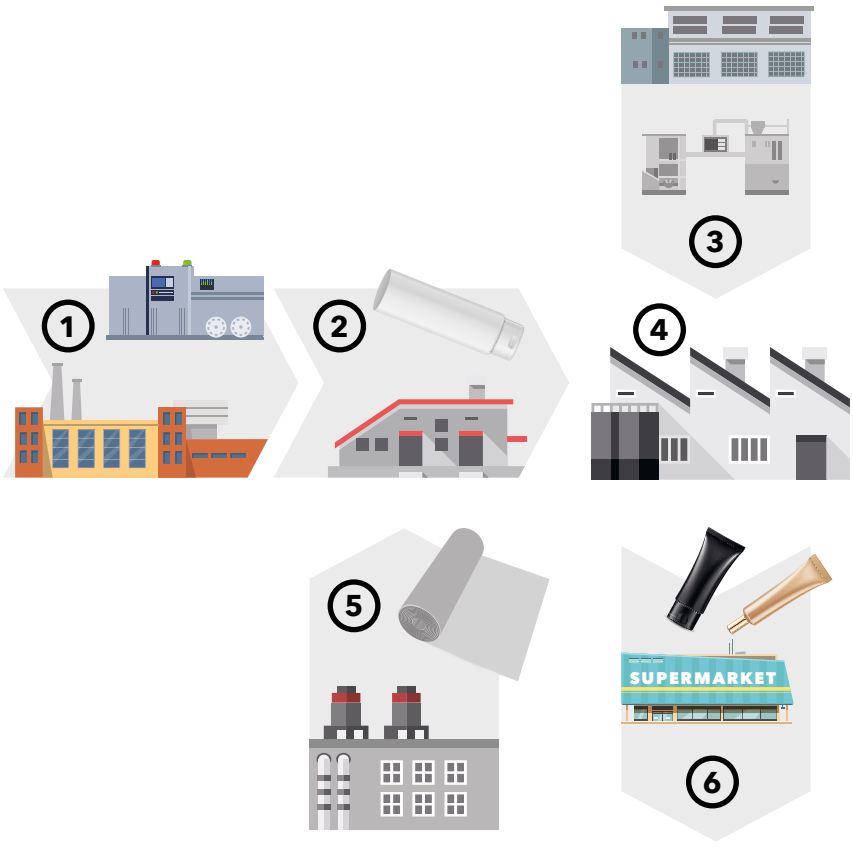
The search for environmentally friendly packaging – including cardboard tubes – is the driving force behind innovations in material technology and has accelerated the development of new packaging solutions.

Value-Added Chain

The value chain from manufactured tubes to filled and sealed tubes is made up of a variety of stakeholders.

We distinguish between:

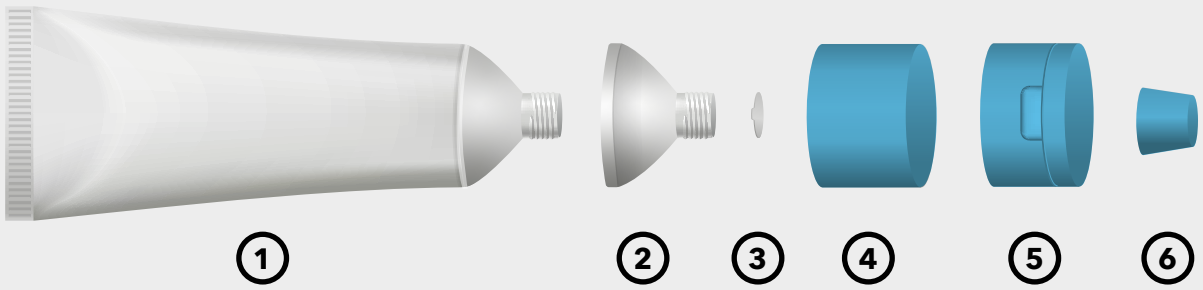
1. Manufacturers of machines and systems for tube blank production (empty tubes)
   e. g. PackSys Global AG, Breyer GmbH, Aisa Automation Industrielle SA
2. Manufacturers of tubes (tube blanks or empty tubes)
   e. g. EPL Global Ltd., Berry Global Gr, Hoffmann Neopac AG, Österreichische Blechwarenfabrik Pirlo GmbH & CO KG, E2Global Inc., Zálesí Verpackung AG, Permapack AG, ALBÉA Group
3. Manufacturers of tube filling and welding machines
   e. g. Norden Machinery AB, TGM Technomachines s. r. L., IWK Verpackungstechnik GmbH, Citus Kalix
4. Manufacturers of cosmetic products including toothpaste etc. and co-packers
   e. g. Colgate-Palmolive Company, Unilever plc, L'Oréal S.A., Procter & Gamble Company
5. Tube raw material manufacturers and suppliers
   e. g. DuPont, BASF, Sabic, Dow Chemical, Rose Plastic AG, Solvay SA
6. Retailers including supermarkets, drugstores, chemists, hardware stores etc.



3. Tube Manufacturing

A range of different materials, technologies (processes) and machines are used in tube manufacturing. These are described in detail below.

Tube Components



After welding, the tube end is either smooth or fluted. Cutting or stamping can produce straight, curved or serrated versions. Tube ends can also have very creative shapes.

1. tube shell or tube body
2. tube head with tube shoulder
3. top seal
4. cylindrical cap
5. flip-top cap
6. conical cap

Tube Materials

In general tubes have aluminum or plastic barriers. These are called ABL tubes (Aluminum Barrier Laminate), PBL tubes (Plastic Barrier Laminate) and COEX tubes. COEX stands for co-extruded tubes. These have a different manufacturing process compared to “normal” plastic tubes.



ABL Tubes

ABL tubes have several plastic layers. These can be different polyolefins. Polyolefins have two main groups: Polyethylene and polypropylene The most widely used are polyethylenes. And these have subgroups with different lengths of polymer chains like LLDPE, LDPE, MDPE and HDPE.

There are also polypropylene (PP) and their recycled subgroups like PCR (Post-Consumer-Recycled) and PIR (Post-Industrial-Recycled). Aluminum foil is always used as a barrier. It protects the filling from the effects of light, air and humidity and prevents the product from picking up aromas from other packing layers or the environment. The copolymer layer is the connection between the aluminum film and the polyolefin, known as the bonding agent. These plastic-metal tubes meet packaging requirements for cosmetic and pharmaceutical products. They are most commonly used for toothpaste packaging, but also for creams, gels, lotions and pastes.

One of the key characteristics of ABL tubes is the ability to maintain its "squeezed shape". In other words, they **do not return to their original shape after squeezing** and are therefore ideal for products which require precise dosing.

PBL Tubes

Like ABL tubes, PBL tubes have several plastic layers. But, they do not contain aluminum barriers and can also be made of organic-based plastics, made of plant fibers (e. g. sugar cane). Up to seven plastic layers can be used to make PBL tubes.

Instead of the aluminum film used in ABL tubes, an ethylene vinyl alcohol film (EVOH) is used as a barrier in PBL tubes. This barrier prevents oxygen and light from getting into the product and oils from migrating from the product into other layers. When manufacturing PBL tubes, the EVOH film is first laminated with other plastics (e. g. polyethylene) to form a multilayered film.

The film is then cut and shaped into a tube. The long edges of the tube are then welded together to form a longitudinal seam, forming the tube body. Finally, the tube body is then welded to the tube head.

One of the most important characteristics of PBL tubes is their ability **to maintain their original round or oval shape.** This means they return to their original shape after squeezing, making them a stable packaging option.



Fig. 1: Machine for the production of ABL, PBL and monomaterial tubes from flat material
PackSys Global AG, 2023

COEX Tubes

During COEX tube manufacture – like PBL tubes – an EVOH barrier, protecting the contents from oxygen transit and the packaging (tube) from oil transit. However, COEX tubes are not made of cut, laminated and sealed plastic films. Instead, they are made of extruded plastics like polyethylene. The result is a seamless tube. Like PBL pipes, COEX tubes **return to their original shape after squeezing.**

ABL, PBL and COEX Tubes Compared

ABL, PBL and co-extruded tubes are used for similar applications in the cosmetics, food and pharmaceutical industries. However, they have different pros and cons and therefore suitable for different products.

ABL tubes are a cost-effective collapsible tube option, offering considerable adaptability. They can be decorated in different ways for a range of different products and brands. They are also an excellent packaging solution for aggressive products like glues, antiseptics, essential oils, creams and toothpaste.

PBL tubes are mainly used for cosmetics, personal hygiene products and drugs. They are also used in the food industry. With no aluminum barrier, they offer a more environmentally-friendly packaging option.

COEX tubes offer a seamless design and flexible barrier options. This way, they are often used for high value cosmetics and personal hygiene products, which need to look particularly attractive on the shelves.

COEX are also particularly suited to packaging for food and pharmaceutical products. They extend the shelf life of products, prevent odor leakage and tube deformation due to the contents.

In addition to polyolefins (around 90 %), other plastics like polyethylene terephthalate (PET) and polyamide (PA) are used in plastic tube production. This is to improve properties like tube printability (PET) or robustness (PA).



Fig. 2: TopLine co-extrusion system
BREYER GmbH Maschinenfabrik, 2023

Special Case: Monomaterial Tubes

Basically, monomaterial tubes are made of one plastic (usually PE). They also have inner layers made of the same material. The material for the inner layers are oriented (drawn lengthwise) or have a different density. For a tube to be a monomaterial tube, it must contain no more than 5 % extraneous material in addition to one plastic. Monomaterial tubes are generally manufactured in specially designed single screw extruders. In order to make them easier to print, there are monomaterial tubes made of flat material. Like PBL tubes, these are rounded and longitudinally welded. This type of monomaterial tubes are often used for less sensitive products like glue, or as disposable tubes.

Manufacturers have their monomaterial tubes certified to prove their recyclability. For example, this is done through the German Institute *cyclos-HTP GmbH*.

Cardboard Tubes

Tube manufacturers are continuously working on the further development of their products, in particular sustainability, recyclability and the circular economy. In the meantime, more and more manufacturers are focusing on cardboard and paper tubes.

Cardboard tubes have a dual-sided plastic layer cardboard body. The dual-sided coating serves as a barrier and offers equal protection for both the cardboard and the product. Cardboard tubes can also be hot air welded thanks to their plastic coating.

A major disadvantage of cardboard tubes is that they are made of several materials. This makes them difficult to recycle.



Fig. 3: Cardboard tube for cosmetic products
Albéa Group, 2023

4. Empty Tube Manufacture (Tube Bodies, Tube Blanks)

There is a range of tube manufacturing processes. The following two processes have become well established: Extruding and longitudinal seam welding.

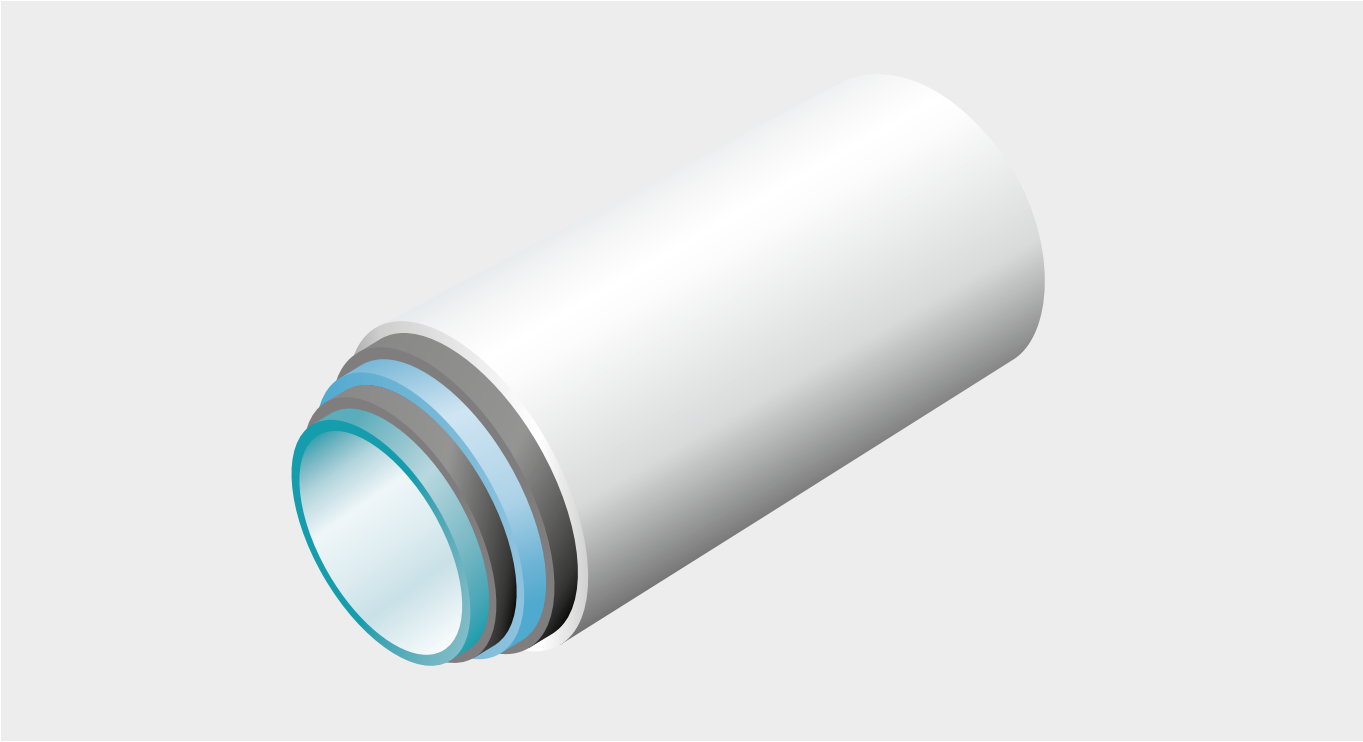
Extruding Tube Bodies

Using modern extruders, manufacturers produce seamless tubes using synthetic granules. This includes single layer tubes in monomaterial and multilayered tubes, or co-extruded PBL tubes.

Several screw extruders are coupled together to make multilayered tube bodies. These each add another plastic layer to the tube pipe.

This creates a seamless and endless pipe which is cut to the required length in a downstream process step. This manufacturing process can produce up to 300 tubes per minute.

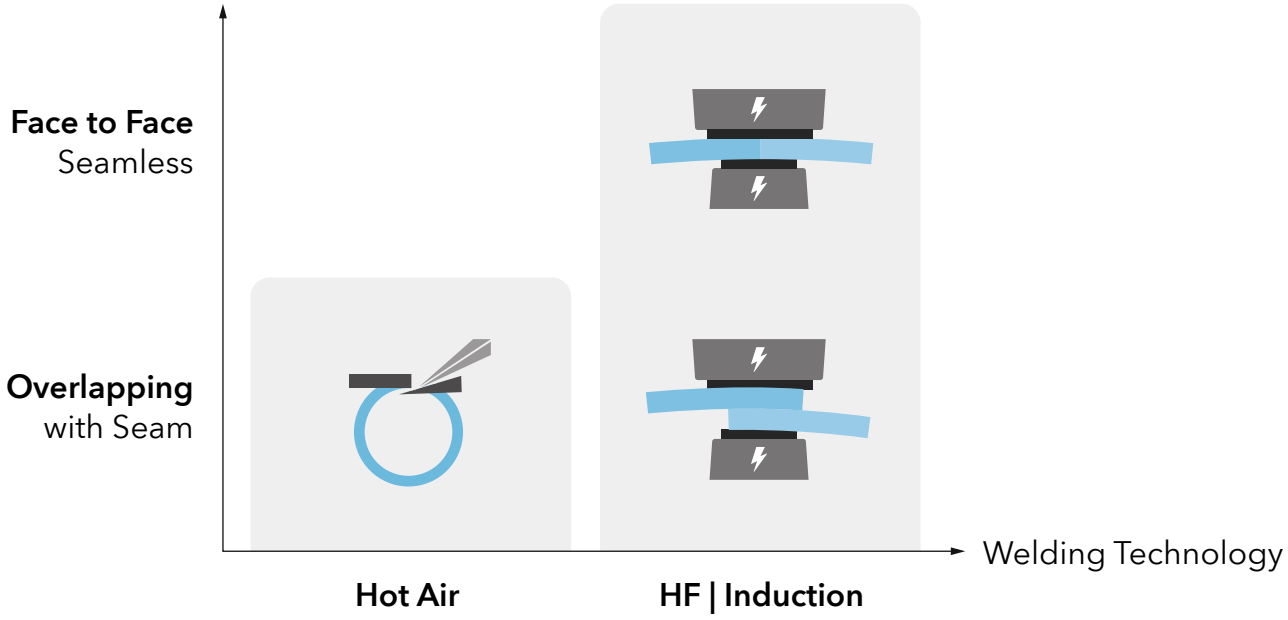
ABL tubes can not yet be made with extruders due to their aluminum barrier.



Tube Body Long Seam Welding

In longitudinal seam welding, previously extruded flat films are initially rounded and then longitudinally welded in tube welding machines. The film can then undergo single layer or multilayer lamination. Both ABL and PBL tube bodies can be made in this way.

The longitudinal seam is either welded with hot air or with a high-frequency process (HF). Modern machines have a capacity of up to 600 tubes per minute.



Printing

Several options are available for tube body printing. The most common are:

- flat material and laminate printing
- 360° pressure printing on tube blanks, e. g. extruded tubes
- film hot stamping of decorative elements

For flat material printing (laminate film) the tube body is made from previously printed material. Co-extruded tubes (e. g. PBL or monomaterial tubes) are printed using the 360° process (e. g. digital printing).



Fig. 4: Machine for printing tube blanks
Hinterkopf GmbH, 2023



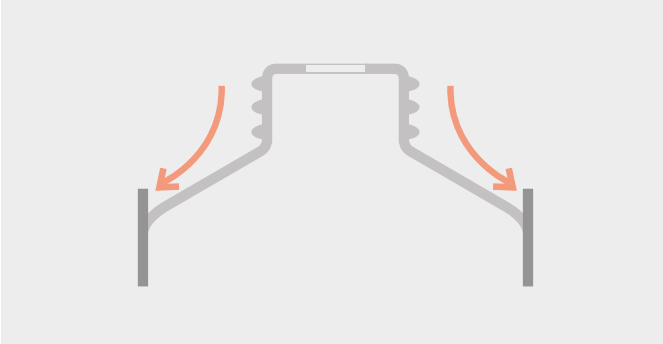
Fig. 5: Explo Cosmetics Tube laminate
Permapack AG, 2023

Mounting the Tube Head

The following processes are the main ones used for mounting the tube head:

- Injection in Injection molding process
- Compression molding
- Welding with hot air
- HF welding

Welding with Hot Air



(1) Heating up the welding area with hot air



(2) Welding the tube head onto the tube body and immediate cooling

Filling and Sealing

Large producers like Procter & Gamble Company, Colgate-Palmolive Company etc. or their co-packers use machines for tube filling and welding. Rapid co-packer lines processing high volumes are available from certain larger OEM. These services include empty tube feeding, filling, welding, packing and palletizing. PBL and ABL tubes are processed here.

PBL and cardboard tubes are growing in popularity due to increasing demand for environmentally-friendly, sustainable packaging.

Hot air continues to be used for welding, regardless of which types of tubes are filled and welded in such high-capacity systems.

5. Machine Designs for Tube Filling and Sealing

Design and structure of machines for filling and welding tubes play a key role in the wear and tear on the machine and have a major impact on output and/or capacity. Machine capacity is measured in parts per minute (ppm).

There are three types of machine design: round, oval or linear composition. The composition and associated welding process play an important role in speed and/or machine capacity. Product properties (viscosity) also influence machine capacity.

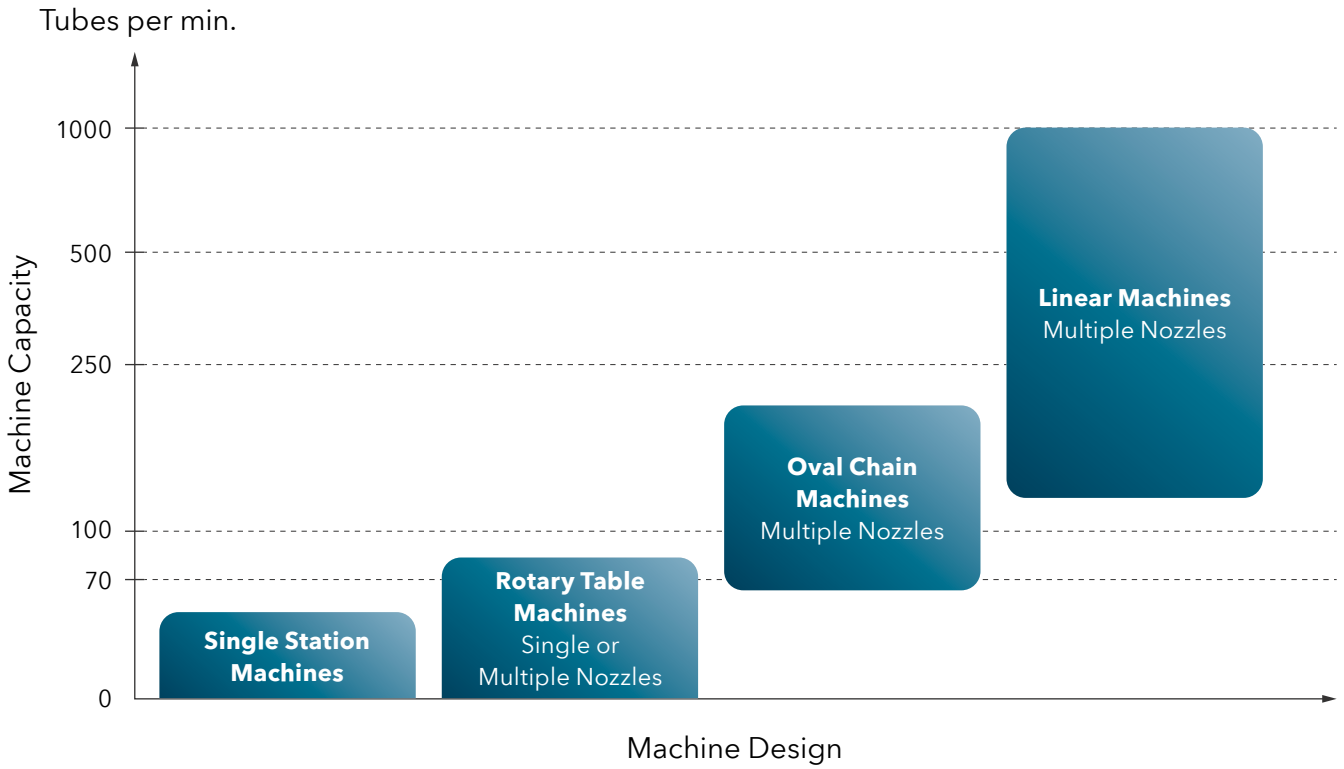
Speed Limitations when Filling

Tubes per Minute	Fluid	Semi-Fluid	Toothpaste	Viscous	Highly Viscous
Per Filling Station (Guide)	25–40	40–60	70–90	65–80	15–30

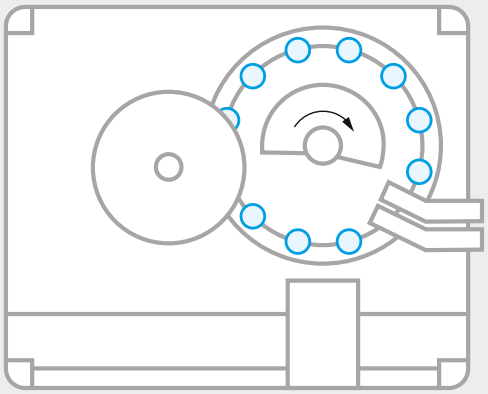
Notes on Speed Limitations when Filling

- Fluid products, e. g. cosmetics and hygiene products like shampoo and shower gels tend to splash, so they cannot be filled at a high rate.
- Semi-fluid products, e. g. cosmetics like hair gel and body lotion or adhesives like wood glue, splash less so they can be filled more quickly.
- On account of their viscosity, toothpaste and viscous products are generally the easiest product to fill because they do not splash and are easily dosed. Therefore, they can be processed at higher speeds in filling machines.
- High viscose products, e. g. fillers and pigment pastes or high viscous food like wasabi also do not splash very much, although their consistency requires a special filling nozzle.

The various machine designs and their capacities are shown in the following graphic.



Filling and Welding Machines with Round Format (Rotary Table Machines)



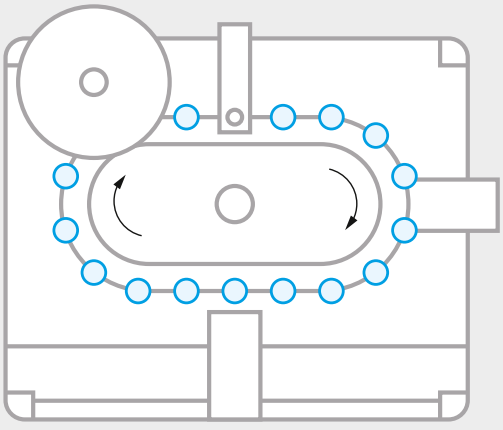
The graphic shows the standard structure of a filling and welding machine with round structure (12 position rotary table).

Filling and welding machines with a round structure are designed for **smaller machine capacities**. Empty tubes are fed into the filling machine by hand. The smallest version of these machines as integrated as an individual station or works with a simple rotary synchronized table with several stations.

Machine capacity is 40 to 80 tubes per minute.

The welding process is either ultrasonic, heater bars or hot air.

Filling and Welding Machines with Oval Format



In oval structured filling and welding machines, the tube holders are connected together via an oval chain.

Filling and welding machines with an oval structure designed are for **medium machine capacities**. Here, machine designs with round and oval structures can overlap. Semi or fully automatic systems are used.

In medium machine capacities, empty tubes are brought into the machine in packets or via a feeder system.

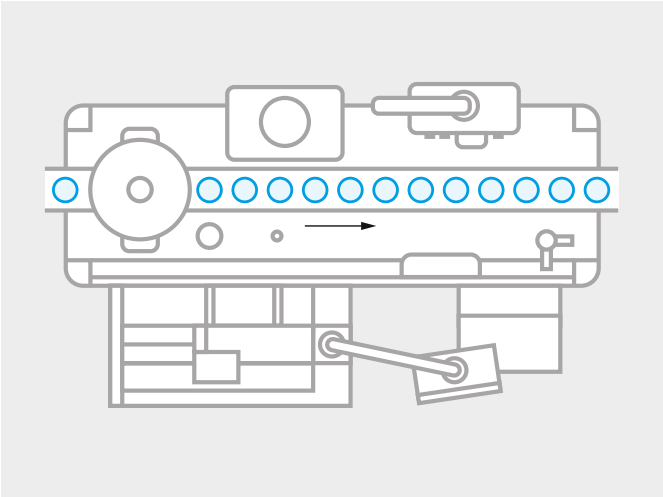
Machine capacity is 80 to 200 tubes per minute.

Tubes in these machines are often welded with hot air. Ultrasonic technology is more rarely used. There are single or double station welding stations.

Single stations: Welding and cutting take place sequentially in one station.

Double stations: Welding and cutting are synchronized at two different stations.

Filling and Welding Machines with Linear Format



In a linear structured filling and welding machine, the tubes are fed through the machine in a linear way in a synchronized process.

This type of high-capacity machines are on fully automatic filling lines. Here, empty tubes are fed in with a robot or handling device. This way, the robot's capacity is synchronized with the machine stations.

In fully automatic machines, the welded tubes are regularly packed into the corresponding cardboard boxes and then palleted directly, following filling and welding.

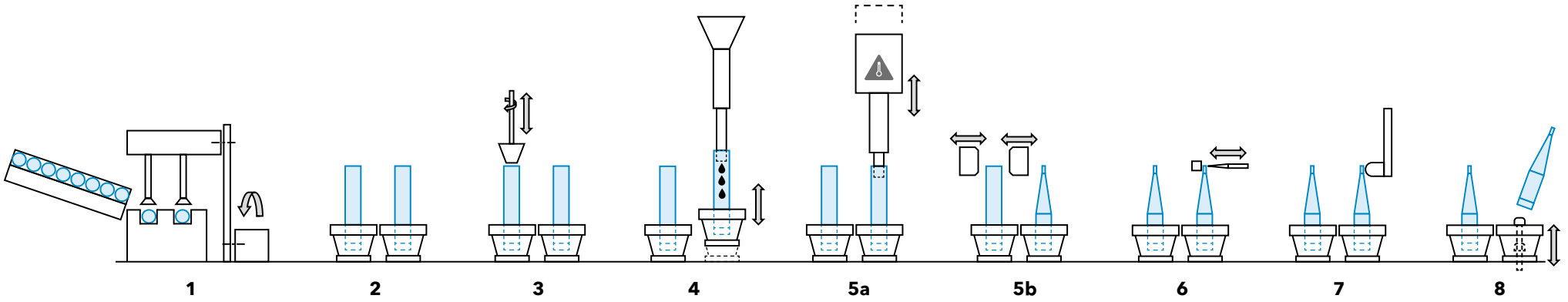
Hot air is used exclusively for tube welding because this is the only technology compatible with the machine capacity and/or speed. The heating time for tube welding is approx. 0.2 seconds.

A standard application for this type of system is filling toothpaste.

Machine capacity is up to 1000 tubes per minute.

6. Process in Tube Filling and Welding Machines

Although the machine concepts differ from one another, the individual process steps in tube filling and sealing are always the same.
The following process steps are carried out in the individual stations of machines for tube filling and sealing:



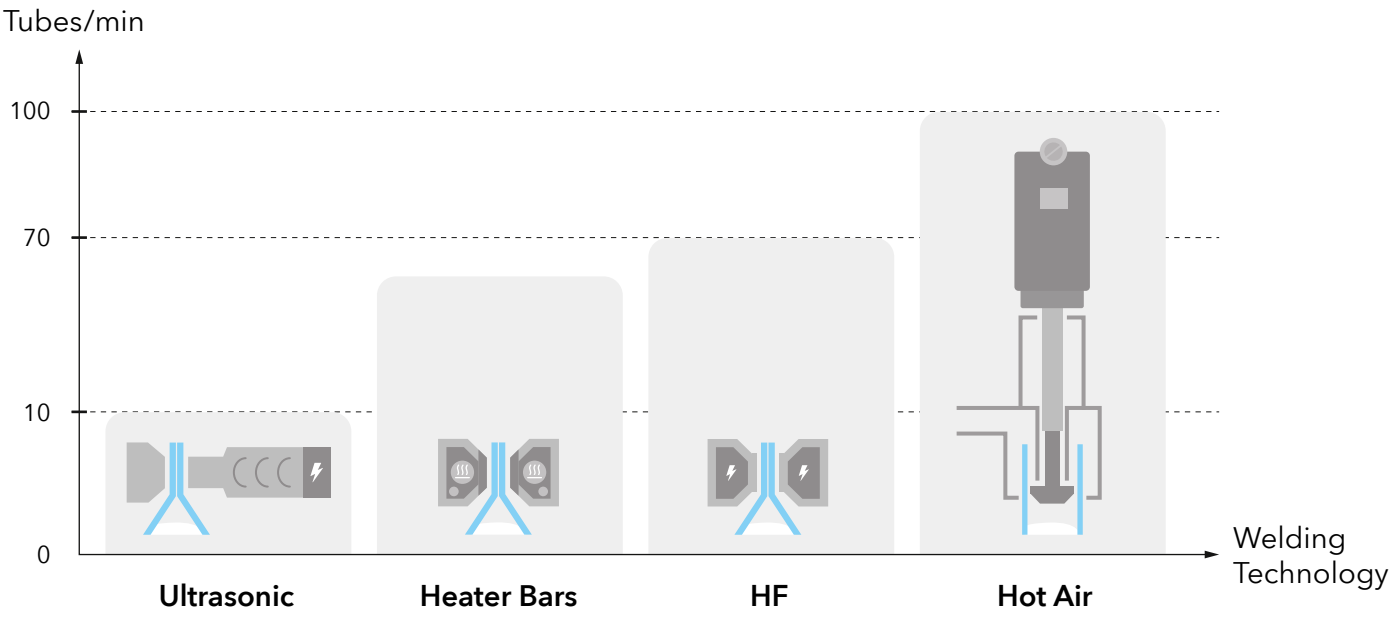
1. Tube magazine: The empty tubes are prepared.
2. Feeding: The tubes are packed in the tube holder.
3. Adjusting and calibrating the tube opening: The tubes are positioned using the printer's mark or the pharma code with a rotating device. Tube opening calibration takes place at the same time to the exact diameter.
4. Filling: The tubes are filled with one or more filling cylinder.
5. Welding: The tubes are welded with the relevant process (hot air, ultrasonic, heater bar, high-frequency HF).
6. Cutting: The sealed seam generated during welding on the tube end is cut away.
7. Stamping: Batch number and expiry date are stamped or printed on the tubes.
8. Ejection: The finished tubes are ejected.
9. Packaging: This process step varies depending on the machine design. Packaging is generally done manually on round synchronized tables. On linear systems, tube packaging in boxes is often done downstream (End of Line Packer).

7. Welding Technologies

As mentioned above, there are four different processes for welding tubes: Ultrasonic, heater bars, high-frequency welding (HF) and hot air.

The choice of technology depends on machine outputs and installation, purchase and maintenance costs.

The following graphic shows the maximum machine output in tubes per minute depending on welding station. This takes into account the different technologies.



The graphic shows the following: If the machine achieves a capacity of 500 tubes per minute for example, 5 hot air welding stations are used in parallel.

Sealing with Ultrasonic

This technology involves injecting ultrasonic sound into the workpiece via a sonotrode* and creating friction. This friction generates heat in most materials (plastics). In order to join two plastics, heat must penetrate the first plastic in order to weld it with the second.

*(*Sonotrodes are tools which move by introducing high-frequency mechanical vibrations in resonance vibrations.)*

Benefits of Ultrasonic Technology in Tube Welding

- Flexible application: Different diameter tubes can be welded without adapting the welding station.
- Fewer stations are required: Heating and welding can be done in one station
- Adjustable seam strength: Seam strength can be adjusted based on the tube material
- Uniform tube edges: Sonotrode and anvil in plane parallel movement
- Optional fixed stop: for exactly the same welding seam thickness

Drawbacks of Ultrasonic Technology in Tube Welding

- Longer process: longer than other welding technologies (1.0–4.0 seconds)
- Polyolefins welding is more complicated: Plastics with self-damping, more often used for tube manufacture, are difficult to weld.
- Material damage and/or burning: moving sonotrodes can damage or burn tube surfaces
- The heating and joining processes cannot be separated, because they take place in the same station, resulting in longer cycle times.



Fig. 6: Sonotronic tube sealing unit, SONOTRONIC Nagel GmbH, 2023

Sealing with Heater Bars

Heater bars are used to weld tubes (heatable gripping devices). These exert pressure on the outer sides of the tube and heat these up uniformly. Heat penetrates the plastic from the tube wall to the inside of the tube. Meanwhile, the tube is sealed under pressure by bringing together the heater bars.

This technology is less efficient than other types of sealing because it takes longer. Reason for this: Heat must penetrate the plastic wall completely in order to also weld the inside of the tube wall. The result of heater bar sealing is also less visually attractive than other technologies.

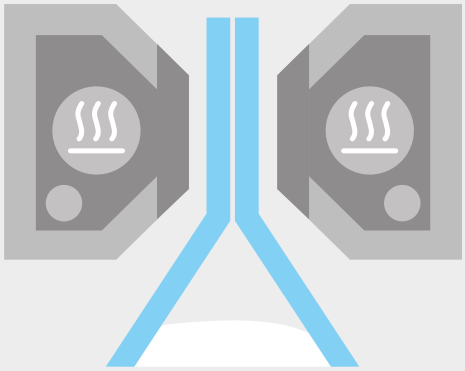
This process is usually done with semiautomatic machines with lower capacities or with manual welding devices.

Advantages of Heater Bar Technology Tube Welding

- Flexible application: Different diameter tubes can be welded without adapting the welding station.
- Economical: simple technology, few control components required
- Fewer stations are required: Heating and welding can be done in one station
- Adjustable seam strength: Seam strength can be adjusted based on the tube material

Disadvantages of Heater Bar Technology Tube Welding

- Slower process: Heat must completely penetrate the plastic wall
- Less visually attractive: irregular weld seam surface
- High maintenance: Plastic residue needs to be removed regularly from bars



Sealing with High Frequency Welding (HF)

For high frequency welding (HF) plastic tubes are bonded under pressure by adding HF energy. The heat required for the welding process is generated through an electromagnetic field. A generator supplies the required energy at a frequency of 27.12 MHz.

The tool used to supply the energy is known as an electrode. The molecules in the material are excited through the electromagnetic field, which generates heat. This heat plasticizes the plastic. This way, heat is generated in the plastic directly, so an external heat supply is not required. The plasticized plastics are joined under pressure. The plastics then cool down by exerting more pressure and a weld seam is generated on the welding surface.

In general: Polyvinyl chloride (PVC) and polyurethane (PU) the most commonly used materials with HF welding.

Advantages of HF Welding in Tube Welding

- Flexible applicable: Different diameter tubes can be welded without adapting the welding station.
- Fewer stations are required: Heating and welding can be done at one station.
- Adjustable seam force: Seam force can be adjusted based on the tube material.

Disadvantages of HF Welding in Tube Welding

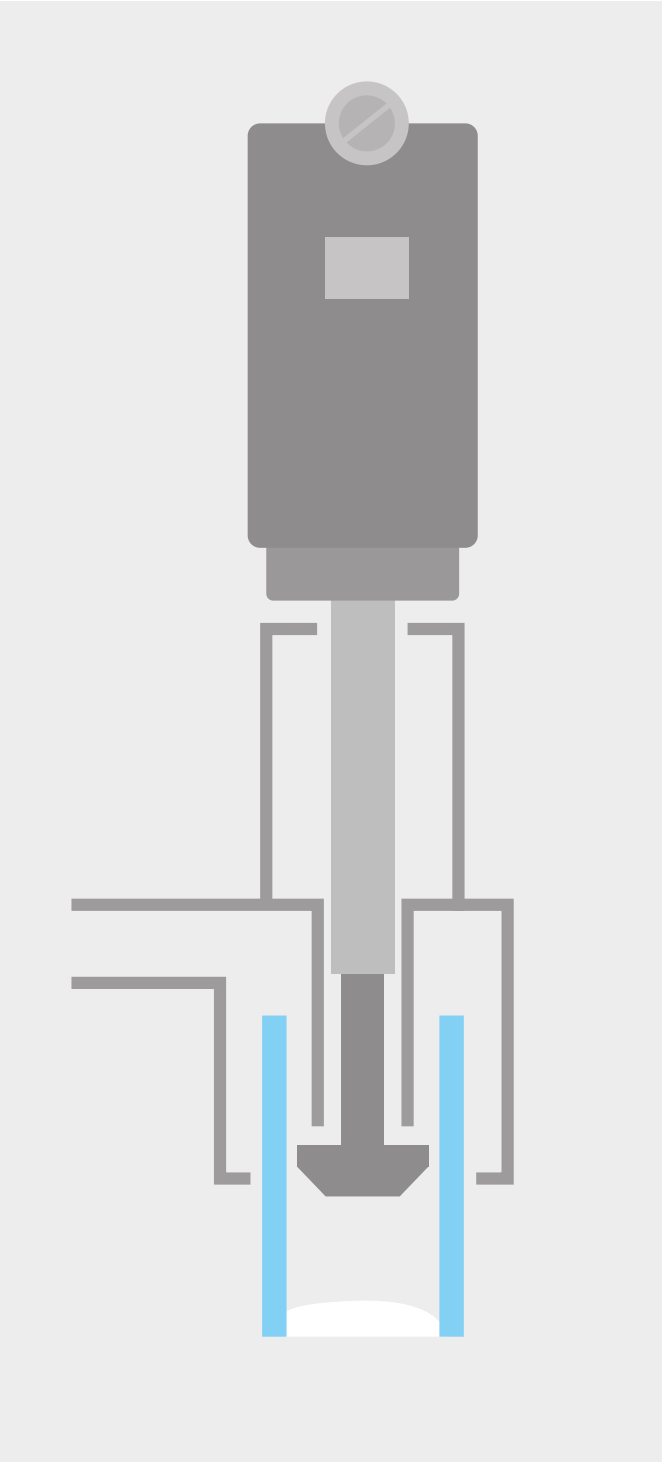
- Limited application: Nonpolar plastics like polyethylene (PE) and polypropylene (PP) cannot be HF welded without an additive.
- The heating and joining processes cannot be separated, because they take place in the same station, resulting in longer cycle times.
- Expensive: The components are expensive.



Welding with Hot Air

Welding tubes with hot air (hot air welding) can be used with all machine designs. Hot air welding is the fastest process compared to other technologies. It is the only technology which can be used efficiently and safely with medium and high capacities.

The average heating time is 0.2 seconds. Here, modern air heater systems are used, which can be adjusted precisely to the degree. *(This process is described in more detail in chapter 9.)*



8. Operation of Modern Air Heater Systems

A modern and efficient air heater is essentially structured as follows:

The air heater has a solid stainless steel outer jacket. Depending on the version, the front side features either a flange or a pipe for attaching the air heater and/or the air supply.

The heating element is located inside as the core of the air heater. The base body of the heating element is made of heat-resistant ceramics because they provide perfect thermal and electrical insulation for the air heater.

This allows the air heater to generate hot air up to 900 °C, depending on the model.

The heating wire forms a heating coil, winding through numerous longitudinal bores of the ceramic body (bent into a spiral or helix). Special alloys are used for this type of heating wire. These alloys feature a relatively high specific electrical resistance and are extremely temperature resistant. Their task is to efficiently convert electrical energy into heat. As soon as current flows through the heating wire, it heats up due to its electrical resistance and thus becomes a heating element.

The formula of electrical power is: $P=R\times I^2$. This means that the heat generated by the heating element is always proportional to the square of current.

Alongside the air heater, a compressed air connection or blower is often required. Its task is to generate the air flow, which is carried through the air heater and heated by it. It is important that the compressed air, air flow and air heater are coordinated with each other. The air heater must always be supplied with a minimum air flow so that its heating elements do not overheat.

The compressed air is usually provided by a compressor. The necessary connections are usually available in industrial operations. The compressed air is usually available between 0.5 and 4.0 bar.

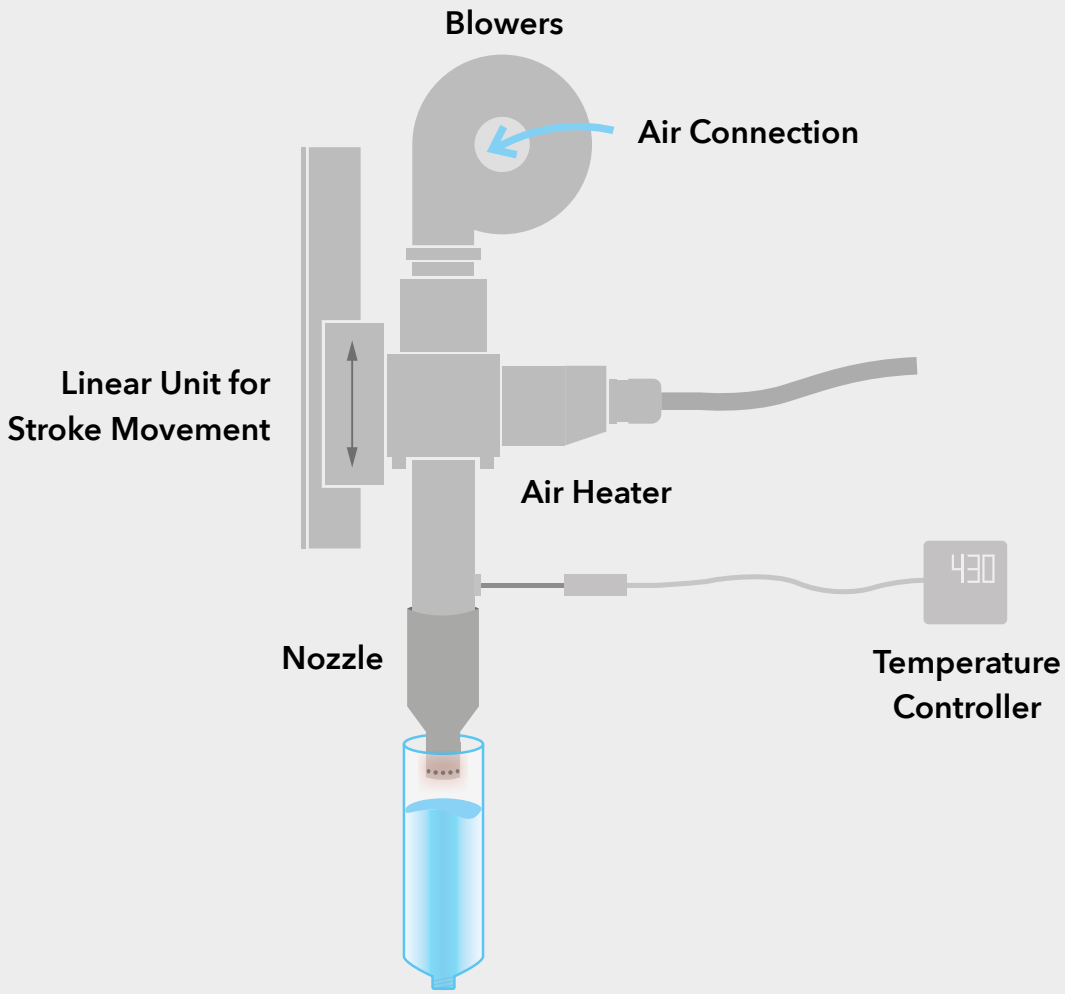
If a blower is used, this is connected with a special air hose to the air heater. Most manufacturers of air heaters carry such hoses in their product range.

The temperature of the air at the outlet of the air heater can generally be controlled in two ways: Either the current of the air heater, i.e. the temperature of the heating wires, or the air supply, is regulated. A small amount of air in the air heater heats up faster and higher than a large amount. Depending on the use of the air heater, the appropriate control must be selected.

A temperature probe measures the temperature at the outlet of the air heater. The probe can be connected to a temperature controller that regulates the current to the air heater.

In addition, the blower can be controlled with a frequency converter (FQ). This means that the blower speed is either increased or reduced, so that the air flow and air volume change.

In many cases, the FQ and temperature controls are connected to a higher-level controller (for example, a PLC) that controls both parameters. This creates a closed control circuit that allows fully automatic operation of the heating system.



9. Welding Tubes with Hot Air

Welding tubes with hot air works as follows:

When the tube is filled with the product to the defined level, it is taken from the filling station to the hot air station. Care is required when filling to ensure the product leaves enough space for subsequent welding. There must not be any residue on the tube end surfaces to be joined, because this would prevent a sealed weld.

There are two stroke movement options for tube welding with hot air: Either the tube is raised upwards to the hot air source or the hot air source is lowered to the tube.

The hot air from the nozzle reaches the inside of the tube, which is coated in or made of PE. The hot air must warm up the inside of the tube for approx. 0.2 s. Then the tube is moved away from the hot air source and is taken to the welding station where the tube is welded. A pressing tool with stamping or a pressing and cutting tool with stamping is used in the welding station *(see process description of 6. process in tube filling and welding machines)*.

There are three relevant parameters when welding plastics: Temperature, pressure and time. Hot air temperature when welding plastic tubes is generally between 400 and 500 °C. Heating up the tube polymer to the welding temperature with hot air lasts approx. 0.2 to 0.3 s. The pressure required for a sealed welding seam is supplied by the pressing and cutting tool and is generally between 0.5 and 1.0 N/mm^2. These systems depend on materials and tube characteristics.

In order to achieve a visually attractive tube closure, with no sharp edges, the welding seam is shaped with a cutting tool after welding. This shape can also be very creative. Depending on substance, virtually any design is possible. Children's toothpaste with little ears and foot-shaped foot cream, for example.

Air Heater Installation and Nozzle Design

Some machine manufacturers integrate complete air heaters and design the tool (nozzle) individually.

The nozzle plunges to supply the hot air into the tube and opening, without disturbing the product, because the product must not be contaminated or heated by the nozzle. So the nozzle diameter must be adapted to each tube diameter. Unless a special tube shape needs to be made, the air outlet openings on the nozzle need to be adapted to each shape. The air heater always stays the same, however.



There are many types of nozzles to supply the welding seam with hot air as efficiently as possible.

The nozzle design for tube welding must ensure that hot air does not reach and/or disturb the product. The outside of the nozzle is usually cooled (water or air) to prevent the tool from getting slowly heated up.

Fig. 7: Nozzles for different tube diameters, Manufacturing Support & Design Ltd., 2023

Ceramic Heating Element Installation

There are also machine manufacturers however, who exclusively use an assembly of air heaters. The assembly comprises a ceramic heating element and a “Micatube”. The heating element transforms the cold air into hot air using electrical resistance. The Micatube is a mineral fiber pipe which ensures excellent dielectric strength. An individual air heater is then designed from this assembly.

With this type of air heater, the hot air is usually taken away through a chimney. Alternatively, the hot air can be removed using an extractor-blower.

In order to be able to recycle the energy from the hot air, the blower must be designed for these high temperatures. Then the hot air can be returned to the process with the right air heaters, resulting in considerable energy savings. We will explain how hot air recycling works in a separate expertise set to be published by the end of 2023.

10. Hot Air Welding Operating Costs and Potential Savings

Operating costs arise from energy consumption during hot air tube welding. These are reduced by dispensing with compressed air and recycling the hot air.

Air Heater Operation with Compressed Air

The air heaters are often connected to the compressed air network. Compressed air generally comes from screw compressors. Screw compressors are a type of gas compressor, where main and auxiliary rotors turn in opposite directions. The V shape of the rotors means that the distance between the rotors is always decreasing, compacting the air. The usual pressure of a compressed air network is around 6.0 bar (positive pressure).

At first sight, compressed air looks like a simple solution to ensure air supply to air heaters. There are several reasons for this: First, compressed air is available in most production operations, because many production machines have integrated pneumatic elements like cylinders and valves which require compressed air. This also means no additional blowers are required to operate the air heaters. This slightly reduces the purchase price of tube welding machines with compressed air supply to the air heaters. For this reason, mechanical engineers often use compressed air to operate air heaters.

Because their investment costs are lower when blowers are not required. This makes them more competitive, because machine operators increasingly take the purchase costs into account for new investments.

However, if we look at the total operating costs for the machine (Total Cost of Ownership, TCO) we can see that energy costs for machines using compressed air for their air heaters are considerably higher than those which use blowers.

Machine operators are therefore advised to look into operating costs as well as purchase costs when making their investment decisions. Because the higher purchase costs of approx. EUR 2000 are amortized with three shift work (20 hours a day) through energy savings after 175 days, so after about one half year. Although the amortization time it is highly dependent on the cost of electricity. The difference of EUR 0.57 per hour between compressed air and blower costs was taken into account for this calculation.

The following table shows operating costs for air heaters with compressed air and blowers.

Operating Cost Comparison

Power	[W]	**2000**	**3300**
Operating temperature	[°C]	450	450
Device flow rate	[l/min]	230	380
	[m^3/h]	13.8	22.8
Flow rate @ 50 Hz	[m^3/min]	0.49	0.49
	[m^3/h]	29.4	29.4
Motor output	[kW]	4	4
Energy consumption/ m^3 compressed air	[kWh/m^3]	0.136	0.136
Blower	[kW]	0.25	0.25
Energy costs	[EUR/kWh]	0.2	0.2
Compressed air costs	[EUR/m^3]	0.027	0.027
Appliance operation costs compressed air	**[EUR/h]**	**0.38**	**0.62**
Appliance operation costs blower	**[EUR/h]**	**0.05**	**0.05**
Cost factor compressed air/blower	**[-]**	**7.6**	**12.4**

Important: The above table is based on a 4 kW capacity compressor and a flow rate of 29.4 [m^3/h]. Standard leakages in the compressed air network in the sector were taken into account.

In the table, you can see that working with compressed air compared to a blower coordinated with the air heater is up to 12 times more expensive, depending on capacity and required airflow.

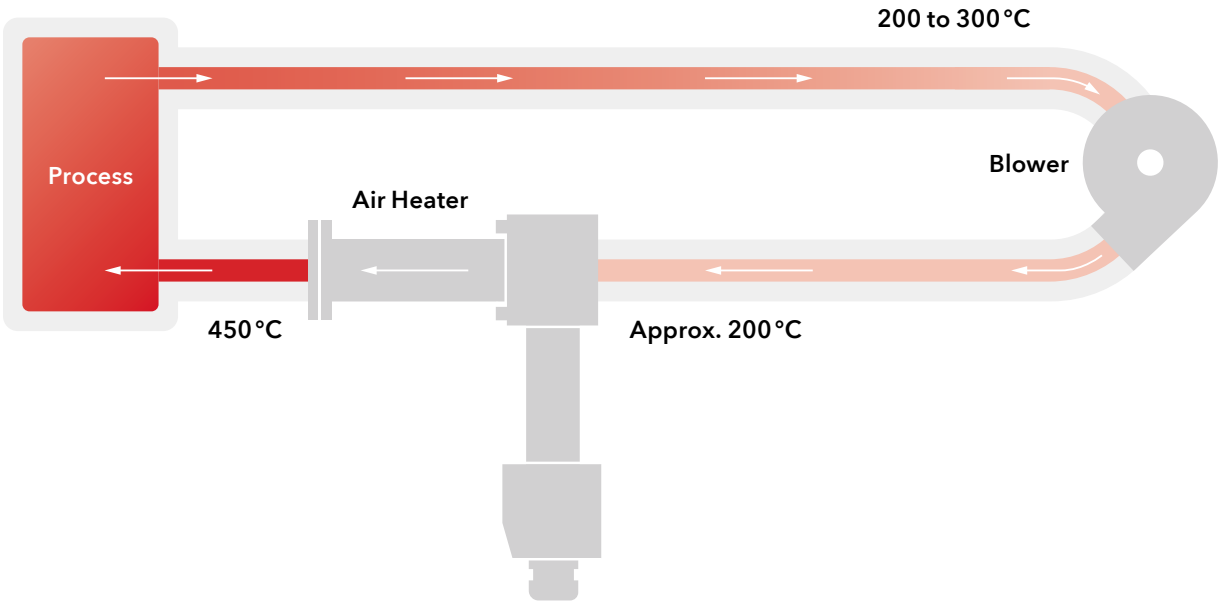
Conventional air heaters also guarantee faultless operation with up to a max. of 1.0 bar pressure. If the general conventional network pressure of 6.0 bar is not sufficiently reduced and the air heater exposed to excess pressure, this obviously reduces the life-time of its heating element. This results in higher spare parts costs, which is another issue influencing the TCO. In contrast, if the right blower is coordinated with the air heater operating point, this extends its life cycle.

Energy Saving Opportunities

The hot air required for welding plastic tubes must be led away immediately after acting on the inside of the tube. This is to prevent warming or contaminating the filled product. The outside of the tube is usually cooled with water or air at the same time.

The air taken away still has a temperature of between 200 and 300 °C. Here lies considerable energy saving potential if the blowers used can recirculate the air. Because these blowers can operate with an inlet air temperature of up to 350 °C. So it is worth using the hot discharged air to preheat the incoming air on the blower.

Hot Air Recycling with Air Heaters and Blowers from Leister



For example, if the incoming air is preheated to 200 °C, the resulting energy savings are around EUR 1241 per year and per blower. See calculation in the following table:

Requirements
Machine activity: 24 h/day, 250 days/year
Air flow: 380 l/min

	Required Power	Energy Consumption per Year	Savings
no Recirculation **T1:** 20 °C **T2:** 450 °C	3.3 kW	19 772 kWh/year	
with Recirculation **T1:** 200 °C **T2:** 450 °C	1.9 kW	11 495 kWh/year	**Difference:** 8277 kWh **Price per kWh*:** EUR 0.15 **Savings:** EUR 1241.45

* The electricity price for 1 kWh for industrial applications is subject to wide fluctuations.

11. Pros and Cons of Different Technologies

Below is a comparison of the pros and cons of each tube welding technology.

Criteria	Ultrasonic	Heater Bars	High Frequency (HF)	Hot Air
Purchase Costs for Components	− high	+ low	− high	+/− medium
Use (Tube Type)	+/− ABL +/− PBL −/− Monomaterial tubes +/− Cardboard tubes	+/− ABL + PBL +/− Monomaterial tubes +/− Cardboard tubes	+/+ ABL +/− PBL −/− Monomaterial tubes −/− Cardboard tubes	+/+ ABL +/+ PBL +/+ Monomaterial tubes +/+ Cardboard tubes
Format Parts Required	+ no	+ no	+ no	− yes
Hot Air Discharge Required	+ no	+ no	+ no	− yes

Criteria	Ultrasonic	Heater Bars	High Frequency (HF)	Hot Air
Commissioning	⊖ difficult, because many parameters need to be taken into account	⊕ simple, because only the heater bar temperature needs to be set	⊖ difficult, because many parameters need to be taken into account	⊕ simpler than ultrasonic and HF ⊖ more complex than heater bars
Machine Integration (Technical/Commercial)	⊖ complex	⊕ simple	⊖ complex	⊕⊖ medium-complexity
Process Safety	⊕ good	⊕⊖ medium, because the heat is brought from the exterior exclusively	⊕ good	⊕ good
Welding Speed per Station in Tubes per Minute	approx. 10	approx. 60	approx. 70	max. 100
Welding Seam Appearance	⊕⊖ medium, outside can be damaged from vibrations	⊖ defective, because surface is rough and heater bars stick to tube plastic and leave marks	⊕ good	⊕ good
Welding Seam Quality	⊕ good	⊕ good	⊕ good	⊕ good

Criteria	Ultrasonic	Heater Bars	High Frequency (HF)	Hot Air
Safety	⊕ ensured through automation	⊖ no automation, simpler machines operated manually	⊕ ensured through automation	⊕ ensured through automation
Seam Strength Setting Possible	⊕ yes	⊕⊖ limited	⊕ yes	⊕ yes
Spread	⊖ low	⊕ high	⊖ low	⊕⊕ very high
Maintenance	⊕⊖ medium	⊖⊖ higher maintenance and cleaning costs due to residue on heater bars	⊕ low	⊕ low

12. Conclusion

Four different technologies are used to weld plastic tubes. Each one has its own pros and cons. In addition to technical process aspects, the selected welding technologies often have a direct impact on machine manufacturing and/or purchase costs and on operating costs (TCO) which is often even more critical.

Hot air is not only the fastest process, but also offers considerable potential savings in terms of energy and spare parts. If the hot air generated is not discharged directly into the environment, but used to preheat the process air, considerable savings are possible. The ecological footprint is also reduced.

In the meantime, blowers with recirculation capacity, designed for use with inlet temperatures of up to 350 °C, are available on the market.

Announcement: In an expertise set to be published at the end of 2023, we will take a detailed look at how efficient and environmentally-friendly recirculation solutions for air heaters need to be designed. So the focus is on sustainability and potential operating cost savings alongside the technical solution.

13. Outlook

In order to reduce the CO_2 footprint and produce in a more environmentally-friendly and resource-saving manner, new tube materials are being researched around the world. Here, the focus is on:

- Using fewer different materials, which are easier to recycle
- Biodegradable materials, e. g. cardboard or paper tubes and bio plastics
- Replacing aluminum barriers with suitable plastics
- Using blowers instead of compressed air to reduce energy and operating costs
- Hot air recycling using temperature-resistant air heaters and blowers (more on this in a subsequent expertise)



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Figure 2 — TopLine co-extrusion system, BREYER GmbH Maschinenfabrik, 2023 www.breyer-extr.com

Figure 3 — Cardboard tube for cosmetic products, Albéa Group, 2023 www.albea-group.com

Figure 4 — Machine for printing tube blanks Hinterkopf GmbH, Hinterkopf GmbH, 2023 www.hinterkopf.de

Figure 5 — Explo Cosmetics Tube laminate Permapack AG, 2023 www.permapack.ch

Figure 6 — Sonotronic tube sealing unit, SONOTRONIC Nagel GmbH, 2023 www.sonotronic.de

Figure 7 — Nozzles for different tube diameters, Manufacturing Support & Design Ltd., 2023 www.msd-ltd.co.uk

Contact



Markus Lipp
Head of Business Development
Leister Technologies AG

+41 41 662 79 47
markus.lipp@leister.com



Pius Enz
Head of Business Line Process Heat
Leister Technologies AG

+41 41 662 75 71
pius.enz@leister.com

Editorial and Media Contact
Silke Landtwing, Corporate Communication Manager, Leister AG

+41 41 662 79 27
silke.landtwing@leister.com

Layout Design
Patrick Lussi, Graphic Designer, Leister Technologies AG

+41 41 662 87 18
patrick.lussi@leister.com

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© Leister AG
Galileo-Strasse 10
6056 Kaegiswil
Switzerland

leister.com
leister@leister.com
+41 41 662 74 74

LEISTER®
leister.com

Get in touch

Benelux
Leister Technologies Benelux BV
3991 CE Houten / Nederland
+31 (0)30 2199888
info@leister.nl

China
Leister Technologies Ltd. Shanghai
201 109 / PRC
+86 21 6442 2398
leister@leister.cn

Germany
Leister Technologies
Deutschland GmbH
42103 Wuppertal / Germany
+49 (202) 87006-0
info.de@leister.com

India
Leister Technologies India Pvt
600 041 Chennai / India
+91 44 2454 3436
info@leister.in

Italy
Leister Technologies Italia s.r.l.
20054 Segrate / Italia
+39 02 2137647
sales@leister.it

Japan
Leister Technologies KK
Yokohama 222-0033 / Japan
+81 45 477 3637
sales-japan@leister.com

Singapore
Leister Tech Asia Pte. Ltd.
Singapore
+65 9787 8712
info.sg@leister.com

USA
Leister Technologies LLC
Itasca, IL 60143 / USA
+1 855 534 7837
info.usa@leister.com

International Distribution
Leister International AG
+41 41 662 74 74
leister@leister.com

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