Save 50 % Electricity when Thermoforming with IR Heaters – is that Possible?

EXPERTISE | Save Energy in Thermoforming

Authors
Oliver Hinz, Senior Product Manager IH
Silvio Conti, Manager Technology Infrared

Management Summary

Starting situation

Machine builders and users in the plastics processing industry are facing the challenge of saving energy and, with it, lowering their operating costs. They also want to lower their CO_2 emissions.

For thermoforming, the selection of suitable and customized IR heaters for heating the plastic semi-finished products offers great potential for energy savings.

Aims

Operators of thermoforming machines are confronted with increased energy prices, which increase their operating costs. More than ever, therefore, they are focused on saving energy.

Machine builders, for their part, want to fulfill customer needs, while also being in competition with one another and therefore have to offer attractive prices for their thermoforming machines.

Analysis

In this report, we will examine the thermoforming process in sheet-fed machines in order to look for potential energy savings. We will also look more closely at the individual process phases of heating, forming and cooling.

IR radiation is only needed during heating to warm the semi-finished products to forming temperature. Therefore the IR heaters can be switched off during the other process phases. This works with fast-reacting medium-wave metal foil heaters.

Although ceramic heaters do not fulfill this requirement, they are used in a majority of sheet-fed machines due to their low price.

Recommendations

Because users want to save energy, lower operating costs and reduce their CO_2 emissions during thermoforming through an appropriately powered IR heater, we recommend investing in sheet-fed machines with metal foil heaters.

So that machine builders can fulfill this customer requirement, we recommend they use the more expensive IR metal foil heaters. This is because, although they increase the price of the machines, users are prepared to accept the additional costs because they will typically be recouped through energy savings within one year.

Table of Contents

1. Introduction

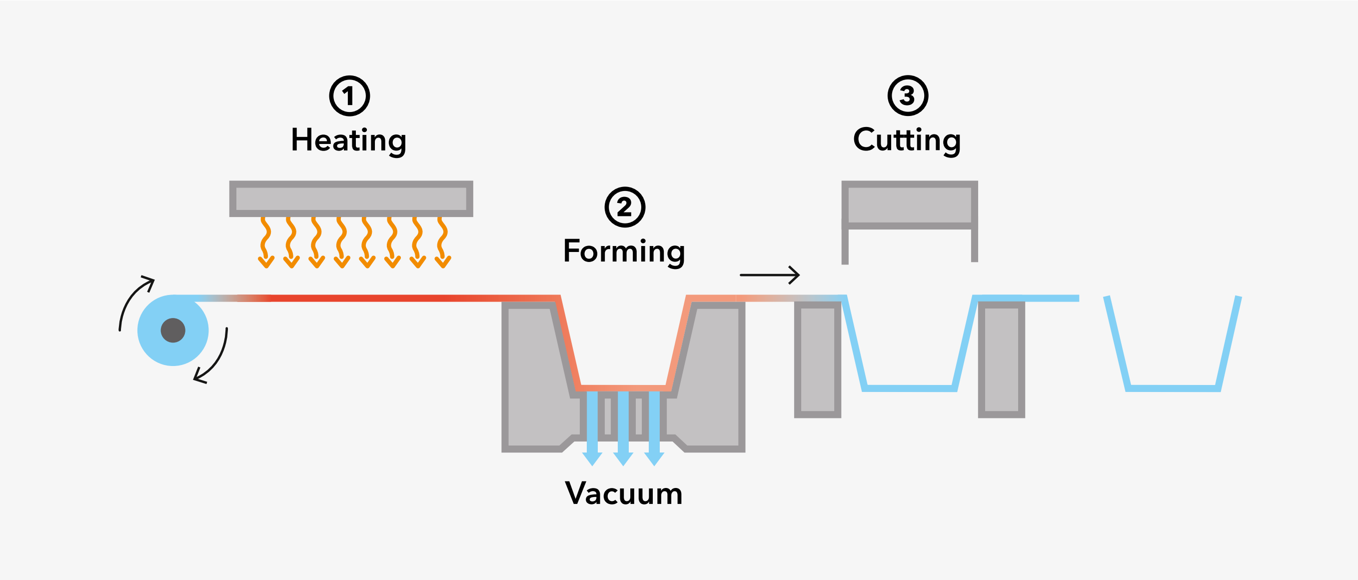
In a wide range of sectors in the plastics manufacturing industry, thermoforming is used to make plastic components for a variety of applications.

The process of thermoforming can be divided into two categories:

- Thermoforming of **thick-walled plastics** (wall thickness 1.5–10.0 mm), also known as heavy gauge thermoforming or sheet-fed thermoforming
- Thermoforming of **thin-walled plastics** (wall thickness 0.2–2.0 mm), also known as thin gauge thermoforming)

Thick-walled plastics are thermoformed on sheet-fed machines, while thin-walled plastics are mainly processed on roller machines. This distinction is important because the production techniques, required machines and applications differ significantly from one another.

Roller Machines

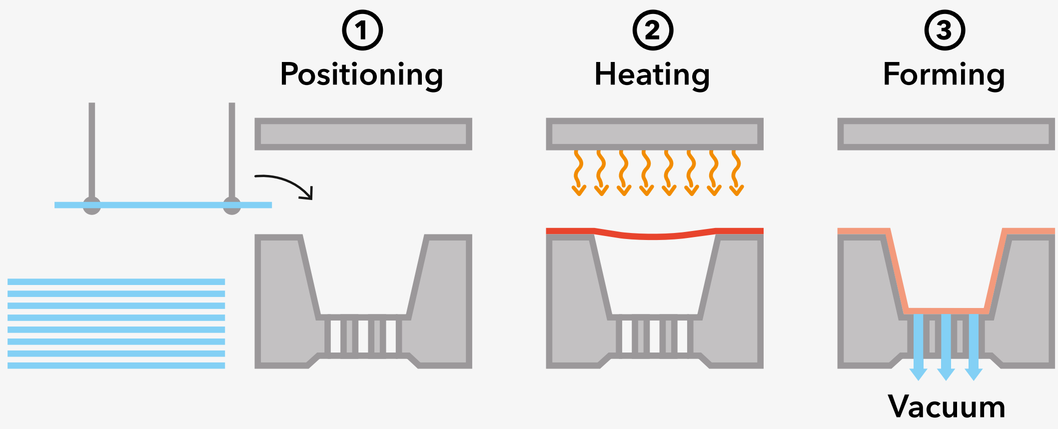


In roller machines, the work steps of heating, forming and cutting occur **simultaneously** at three stations within the machine: The material is heated at station 1, formed and cooled at station 2 and cut at station 3. The endless material is transported in timed stages to the next station. It is a timed, yet continuous, process that is characterized by significant throughput.

Product examples

- Drinking cups
- Yogurt cups
- Inserts for chocolate boxes
- Packaging tubs for food products, such as meat, sausage, fruit or vegetables, etc.
- Packaging inserts for board games

Sheet-Fed Machines



In sheet-fed machines, the work steps heating, forming and cutting are performed **one after the other**. The plate material is positioned, heated, formed and cooled. Unlike the roller machine, infrared heating (IR radiation) is not needed continuously for the heating work step, but rather cyclically. Herein lies the greatest potential for energy savings, as long as the IR heater is powered appropriately.

Product Examples

- Chassis and cover parts for the automobile industry, for example, trucks, motor homes, tractors, forklifts, but also smaller electric vehicles and motorcycles, rooftop boxes for cars (for transporting skis and luggage)
- Cover parts for the aviation industry, for example, luggage flaps and complete interior wall segments for planes, window panes made of polycarbonate or acrylic (PMMA)
- Large components for the construction industry, such as skylights, bathtubs, whirlpools and molded parts for heating and ventilation systems
- Plastic parts for the household goods industry, as well as the entire interiors of refrigerators and freezers, or cover parts for washing machines and dryers

Delimitation

Heating is the process step with the highest energy requirement. That is why this expert report will exclusively focus on the energy-saving potential in the choice of IR heater in plastic thermoforming with sheet-fed machines. Because in these the IR heating will not be permanent, but operated cyclically. And that is precisely what makes it possible to appropriately power the IR heater in order to save electricity and costs.

In roller machines, the IR heating is operated continuously, which is why the potential energy savings are low.

2. Introduction to Thermoforming

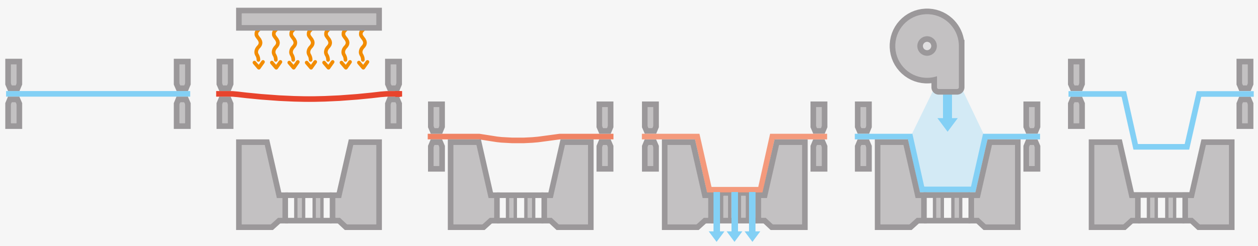
Thermoforming is a process for manufacturing molded parts from plastics. In doing so, a flat, thermoplastic semi-finished product (plate material) is heated to forming temperature. The semi-finished product can be heated via IR radiation, contact or convection. In this whitepaper, we will limit ourselves to heating with infrared radiation, which is by far the most commonly used process (Kaiser 2006: p. 193). Within the forming temperature range, the modulus of elasticity[1] decreases significantly and in this state, also known as a rubber-like elastic state, the semi-finished plastic product can be easily reshaped. In addition, the heated semi-finished product is shaped with the help of a thermoforming tool using either pressure or vacuum. It is then cooled in the thermoforming tool. As soon as the shape is stable, it is removed.

Other names for thermoforming include hot forming, deep drawing and vacuum forming. In vacuum forming, the heated semi-finished product is sucked through negative pressure into the form, in which the part cools (Schwarzmann 2016: p. 1, 6).

[1] The modulus of elasticity (aka e-module) is a measure of the stiffness of a material.

3. Thermoforming Process Steps

The thermoforming process is divided into phases: **Placement | clamping, heating, positioning, forming, cooling and demoulding.** These will be explained below.



1 Placement | Clamping

In order to fix the semi-finished plastic plate for the subsequent processes, it is first placed into the machine and, if necessary, clamped in place.

2 Heating

The temperature of the semi-finished product prior to forming is decisive for the quality of the part. Amorphous thermoplastics must be heated above the glass transition temperature, while semi-crystalline thermoplastics must be heated to the crystalline melting point (Kaiser 2006: p. 193). Higher temperatures lead to overheating and damage to the material, and thus to reduced quality in the part.

The semi-finished product is heated with IR radiation on one or both sides. Heating on both sides reduces the heating time. Heating on both sides is therefore recommended for thick-walled semi-finished products. The semi-finished product is then heated to the forming temperature. At the same time, the surface temperature can be measured contactlessly, for example using a pyrometer.

When furthermore a fast-reacting IR heater is used, the process can be carried out via temperature control. This ensures a high degree of process safety and good reproducibility of the part quality and reliably avoids overheating the part.

③ Positioning

After the heating phase, the heated semi-finished product is positioned on the thermoforming tool. The transfer time has to be as short as possible so that the semi-finished product cools as little as possible during this phase. With one-sided heating and the us of a fast-reacting IR heater *(see Section 4 IR heater for thermoforming)* it is possible to heat directly over the thermoforming tool.
This shortens the positioning time.

④ Forming

The forming process step takes place in the thermoforming tool. Often, pre-stretching with compressed air, a vacuum or a stamp is necessary to ensure a homogeneous distribution of the wall thickness (Bauer et al. 1998: p. 330). The shaping then follows, during which the semi-finished product is closely pressed against the walls of the tool. In vacuum forming, the heated semi-finished product is sucked into the thermoforming tool through negative pressure.

⑤ Cooling

The part which has now been produced from the semi-finished product is kept in the form until it has cooled to below its deformation temperature. In order to expedite cooling, air from the surrounding environment is often blown onto the part. The heat is also dissipated through contact between the part and the walls of the tool. Actively cooled tools can also be used.

⑥ Demoulding

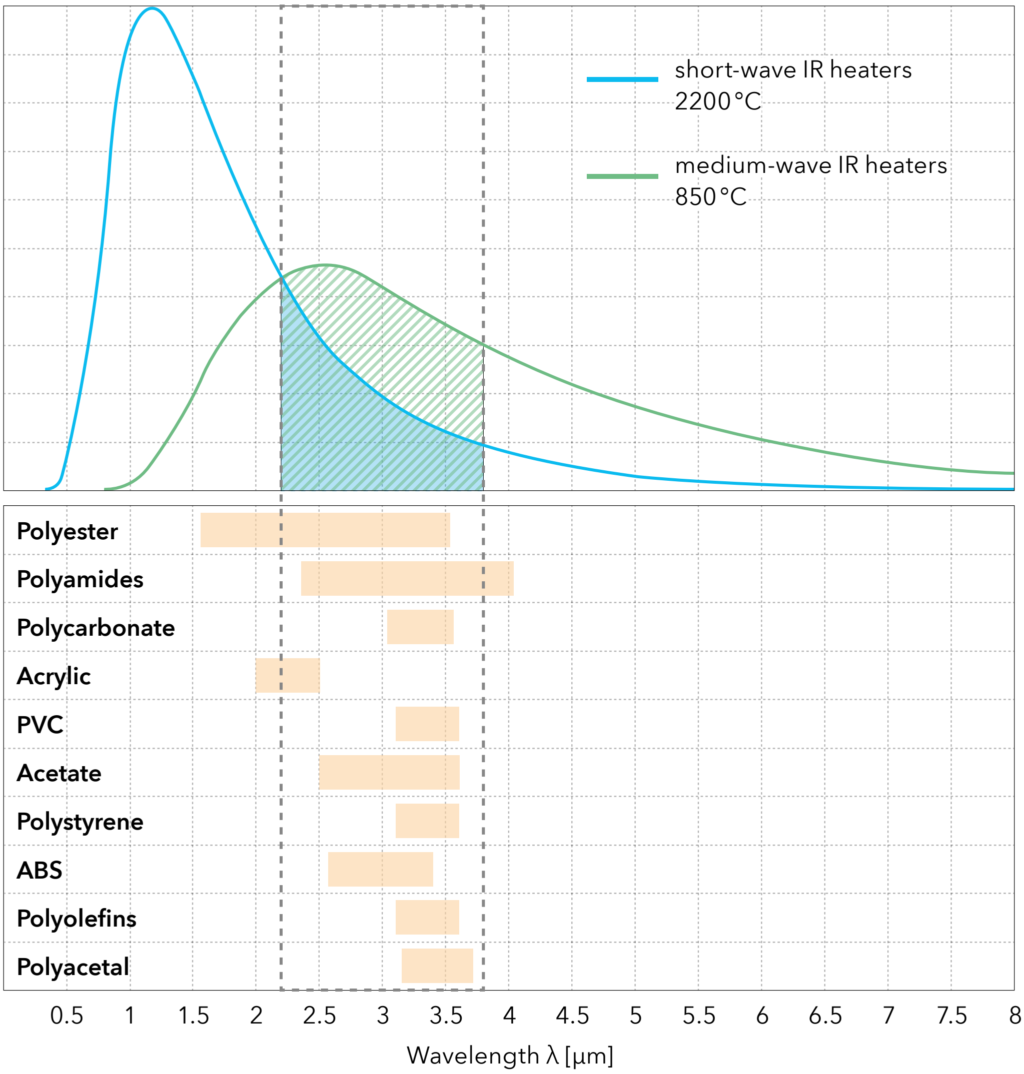
When the part has cooled to below its deformation temperature, i.e. it is stiff enough, it is removed and can be further processed.

4. IR Heaters for Thermoforming

Technical IR heaters are used in the industry when contact-free heating of materials is required. Typical industrial applications include drying paper and textiles, baking paint and hardening other coatings, as well as lamination and plastics thermoforming (Leupen et al. 1989: p. 199).

In thermoforming, IR heating is the most frequently used heating method thanks to its energy efficiency and flexibility. To do so, short or medium-wave IR heaters are used. In terms of short-wave IR heaters, halogen or other glass tube heaters are common, while ceramic, quartz and metal foil heaters are typical for medium wave.

Intensity Distribution and Absorption Bands of Plastics



In selecting the appropriate IR heater, attention must be paid to the absorption bands of the thermoplastics to be heated. These absorption bands are concentrated in two wavelength ranges: 3.2 to 3.9 µm for polyolefins and 1.9 to 3.6 µm for nearly all other thermoplastics. IR heaters with a high intensity within these wavelength ranges are therefore essential for efficiently heating plastics.

IR heaters are identified by their wavelengths. These correspond directly to the temperature of the heater medium or heat source. The heater medium is the material used to emit the IR radiation, for example the metal foil in metal foil heaters.

The higher the temperature of the heater medium, the shorter the wavelength. According to Wien's displacement law, the wavelength is inversely proportional to the absolute temperature in Kelvin.

The German physicist Wilhelm Wien (1864–1928) discovered a correlation in 1896, *Wien's displacement law*, which bears his name:

The wavelength of the most intensive radiation depends only on the temperature of the black body.
The formula is as follows:

$$\lambda_{max} = \frac{b}{T}$$

λ_{max} = Peak wavelength in [µm]
b = Wien's constant = 2897.8 [µmK]
T = absolute temperature in [K]

Short-Wave Glass Tube Heaters

Temperature of the radiation medium
1400–2400 °C

Wavelength of the max. radiation intensity
1.1–1.7 µm

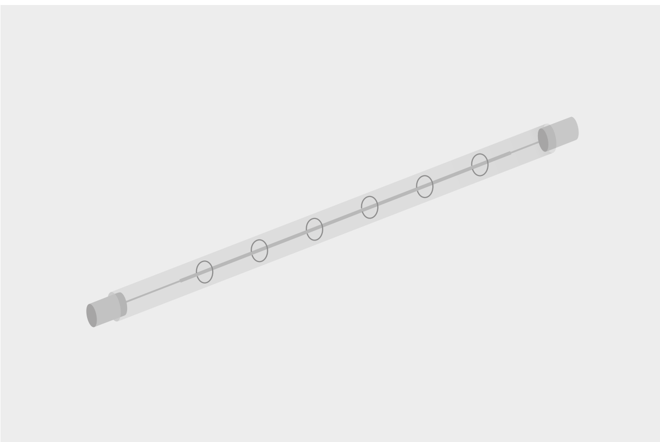
Short-wave glass tube heaters are lamps, mostly in form of rods. The heat source (usually a coil of tungsten wire) is mounted in a quartz glass tube. Due to the high temperature of the heat source, short-wave IR radiation is emitted, the majority of which is transmitted through the quartz glass tube. Due to the low thermal mass of the tungsten wire, these IR heaters have short reaction times. Short-wave IR heaters are also characterized by high energy density of up to 200 kW/m^2. Thermoplastics mainly absorb IR radiation within a wavelength range of 1.9–3.9 µm. For this reason, the efficiency of heating with short-wave radiation is low.

Medium-Wave Ceramic Heaters

Temperature of the radiation medium
600–850 °C

Wavelength of the max. radiation intensity
2.6–3.3 µm

In 1950, the first IR heater with a fully ceramic surface entered the market. The ceramic surface is the radiation medium, but not the heat source. It serves to transmit the IR radiation, i.e. it is heated to the desired temperature with the help of an electric resistance heater. Due to the design, this results in a slow reaction time of approx. 60 seconds or more. Ceramic heaters are wide-spread and are often installed in thermoforming machines. They are available in a wide range of sizes and shapes. The maximum dimensions of individual ceramic heater are approx. 62.5×250.0 mm and 125.0×125.0 mm. Ceramic heaters can be combined into larger heating fields with individual heat zones.



Medium-Wave Quartz Heaters

Temperature of the radiation medium
700–850 °C

Wavelength of the max. radiation intensity
2.6–3.0 µm

Quartz heaters are medium-wave glass tube heaters. Because the short-wave glass tube heaters look similar, these can be easily confused. Unlike short-wave IR heaters, the heat source of the quartz heaters is less hot and emits medium-wave radiation. The majority of medium-wave and all long-wave radiation portions are absorbed by the glass tube. The glass casing is therefore the heater medium, which makes the quartz heater slow. The reaction times of quartz heaters are around 60 seconds, depending on the design. Alongside individual glass tubes (rods), quartz heaters are also available as small modules.
In modules such as there, multiple quartz tubes are installed next to one another, creating a radiating surface. The maximum size of these modules is approx. 62.5×250.0 mm. These modules are similar in dimension, performance and behavior to ceramic heaters. They are wide-spread and are often installed in thermoforming machines.

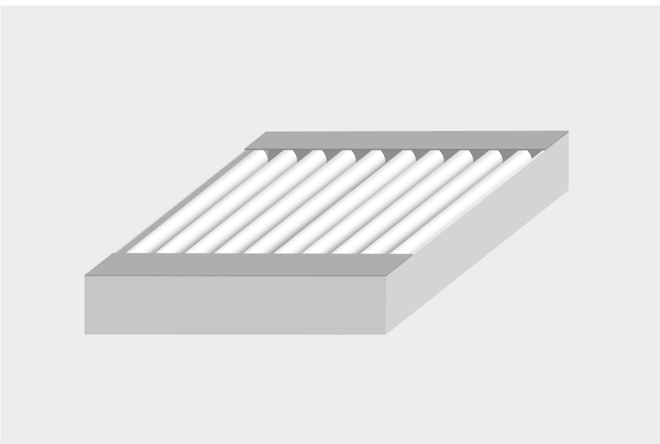
Medium-Wave Metal Foil Heaters

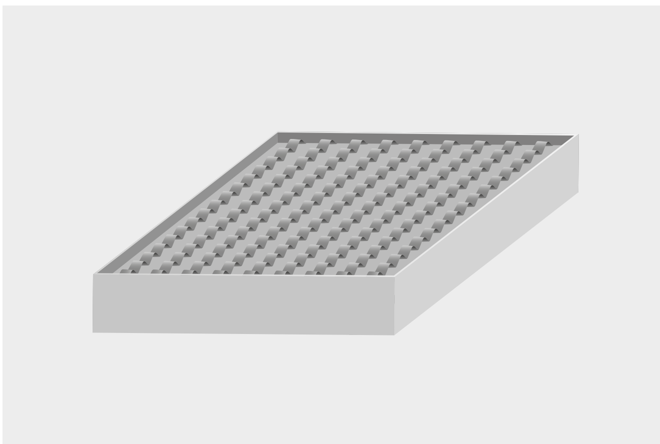
Temperature of the radiation medium
850–900 °C

Wavelength of the max. radiation intensity
2.5–2.6 µm

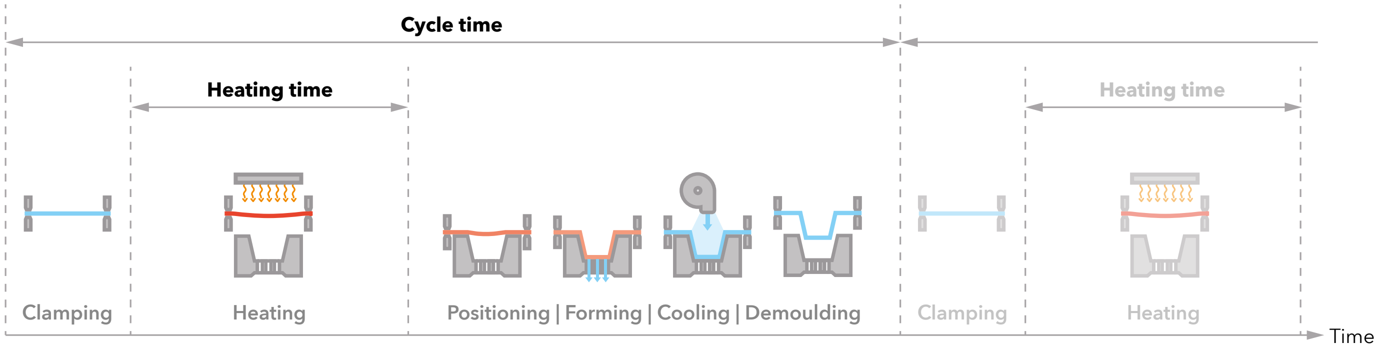
Metal foil heaters are medium-wave IR heaters and have been available on the market since 1970. Their radiation source is a metal foil (aka heating foil) which directly emits medium-wave IR radiation. This means that the metal foil is not covered. Due to the low thermal mass, the reaction time of metal foil heaters is short.

Metal foil heaters are surface heaters. They combine the advantages of a shorter reaction time with medium-wave IR radiation. Due to the wavelength of their emissions, they are ideally suited to heating thermoplastics. Metal foil heaters come in many different sizes and shapes. In thermoforming machines, they are installed as IR modules in sizes ranging from 125.0×125.0 mm to 250.0×250.0 mm. Like ceramic and quartz heaters, metal foil heaters can be used to build up heating fields and combined into individual heating zones.





5. Energy Saving Potential



Heating time and cycle time in the thermoforming process

The standard cycle time for thermoforming processes on sheet-fed machines is 30 seconds to several minutes. However, IR heating is only required during the heating process phase (heating time).

To save energy and cut costs, the IR heater needs to be switched off during the other process phases.

To ensure that the IR emitters cool and heat up again during a cycle, they must have a short reaction time of only a few seconds.

Due to the low thermal mass of their metal foil, metal foil heaters have great potential in this regard. This is because they cool down immediately after switching off and heat up again in a few seconds.

Ceramic heaters have a high thermal mass. In these IR heaters, the entire volume of the ceramic body has to be heated before the maximum radiation intensity (with a heater temperature of 700–850 °C) is reached. This heating process can take up to several minutes. This also applies to cooling.

Due to this long reaction time, briefly switching off the ceramic heater is not an option in processes with typical cycle times of 30 seconds to a few minutes. Ceramic heaters therefore must be operated continuously.

This also means that ceramic heaters use energy in process phases in which heating is not required. They also unnecessarily heat the surrounding environment.

6. Example Calculation of Energy Savings

Thanks to the use of fast-reacting metal foil heaters and the adaption of their control to the process, electricity is saved.

The following calculation illustrates the annual energy consumption of metal foil heaters compared to ceramic heaters. The calculation is based on IR heater fields, each with an output of 50 kW and a cycle time of one minute.

Conditions	
Cycle time	1 min
Heating time	25 s
Stand-by-time (forming, cooling)	35 s
Number of shifts per day	3
Machine hours per shift	7 h
Working days per year	220 d
Machine hours per year	4620 h
Usage of IR-heater power	50 kW
Energy price for 1 kWh (industrial)	0.15 EUR/kWh*

Example Calculation	**Metal Foil IR Heater**	**Ceramic IR Heater**
Heating time	5 s	several minutes
Heater "ON" time per cycle	30 s (incl. 5 s pre-heating)	1 min
Total consumption per day	525 kWh	1050 kWh
Total consumption per year	115 500 kWh	231 000 kWh
Energy costs per year	17 325 EUR	34 650 EUR
Savings per year	**17 325 EUR**	

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

In this example, metal foil heaters are switched on for 30 seconds with a cycle time of one minute. Compared with IR heaters operated continuously, the energy saving amounts to 50 %.

The efficiency of medium-wave metal foil heaters is also higher compared to ceramic heaters. This means that the same radiant energy absorbed by the product is achieved with around 10 % less electricity. This increases the savings still further.

7. Economic Efficiency Calculation

When making investment decisions, not only procurement costs are considered, but also operating costs.

A sheet-fed machine for thermoforming equipped with fast-reacting medium-wave metal foil heaters and an appropriately adapted control system uses less electricity. This saves on energy costs for the operator. With only 50 kW of installed IR output (corresponding to a smaller machine), our example *(Section 6 Example calculation of energy savings)* shows annual savings of 17 325 EUR. Often, the output installed is higher (100–200 kW) and the machines are in use for 10 years or longer, which multiplies the savings.

Both machine operators and the environment benefit from these savings and the lower energy consumption.

On the other hand, machine builders have to weigh the investment, which is five to tentimes higher than for ceramic heaters. The additional costs for metal foil heaters increase the price per machine overall by a maximum of 5 %. However, the investment in a machine with metal foil heat-ers is well worth it for operators. The additional costs are generally recouped within a year thanks to the low energy consumption. The time to recoup costs depends on the machine utilization, the ratio between heating time and cycle time, the IR power installed and the price of electricity.

The following graphic shows the investment and energy costs of metal foil heaters compared to ceramic heaters. The example is based on the assumption that metal foil heaters consume 50 % less electricity during operation than ceramic heaters.

IR Heaters	**Investment Costs**		**Energy Costs per Year**		**Total Costs**
Ceramic Heater	1 €	+	16 €	=	17 €
Metal Foil Heater	5 €	+	8 €	=	13 €

Due to the considerable potential for energy savings during operation, the investment costs are recouped within a short period of time.

8. Time-Controlled or Temperature Regulated Process Control

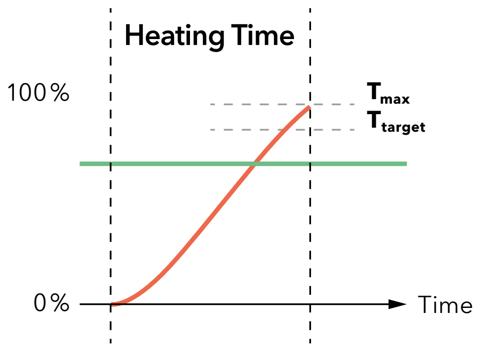
In process management, we distinguish between **time-controlled** and **temperature regulated** processes.

In **time-controlled processes**, the plastic semi-finished product is exposed to the IR radiation for a certain period of time. During this time, the temperature of the semi-finished product rises continuously. If the forming temperature of the semi-finished product has been reached, it must be removed from the radiation area in order to prevent overheating the plastic. In such cases, the IR heater field is moved out of the heating zone and placed in a parked position.

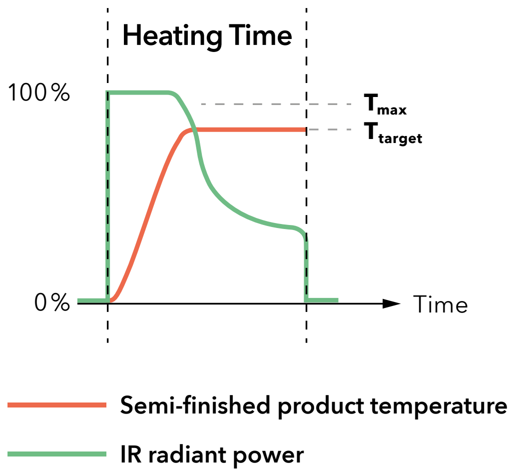
In **temperature regulated processes** the temperature on the surface of the semi-finished product is measured. The IR heaters are regulated via a PID-controller. This ensures that the output of the IR heaters is reduced once the target temperature has been reached so that the temperature of the surface of the plastic semi-finished product remains constant. This prevents the overheating of the plastic. Furthermore, the forming temperature can be reliably achieved, regardless of fluctuations in the surrounding temperature.

Temperature regulated process control can only be realized with IR heaters whose emission intensity that can be adjusted rapidly.

Time-Controlled Process



Temperature Regulated Process



It is good to notice that overheating of the plastic semi-finished product can be reliably prevented through temperature control in a temperature regulated process.

9. Advantages and Disadvantages of Metal Foil Heaters vs Ceramic Heaters

Below, the advantages and disadvantages of metal foil heaters and ceramic heaters in **cyclical thermoforming processes** will be discussed.

Criteria	Metal Foil Heater	Ceramic Heater
Type	✓ Surface heater	✓ Surface heater
Wavelength	✓ medium-wave	✓ medium-wave
Reaction Time	✓ fast	✗ slow
Temperature Control of the Semi-Finished Product	✓ fast and precise	✗ slow
Process Safety	✓ temperature regulated and time-controlled process possible ✓ increased process safety through temperature regulated process	✗ only possible in time-controlled process
Sustainability	✓ less energy consumption through demand-oriented operation	✗ more energy consumption through continuous operation
Operating Costs	✓ low thanks to low energy consumption through appropriate operation	✗ high through high energy consumption in continuous operation
Investment Costs for IR Heater Fields	✗ five to ten times higher than ceramic heaters (recouped through lower operating costs)	✓ five to ten times lower than metal foil heaters
Maintenance	✓ easy replacement of individual modules in the IR heater field possible	✓ easy replacement of individual modules in the IR heater field possible

10. Conclusion

In cyclical thermoforming processes, there is considerable potential for energy savings. Thermoforming machines can take advantage of that with fast-reacting medium-wave IR metal foil heaters. In addition, with metal foil heaters, it is possible to precisely control the temperature of the plastic semi-finished product.

Increasing energy prices and growing awareness of environmental issues, such as climate change, have awakened the need for companies in the plastics processing industry to lower their energy consumption and their CO_2 emissions.

In connection with thermoforming of plastics, this increases the pressure on machine builders to invest in the further development of their machines. When additional costs arise through energy-efficient IR heater technology and temperature control, this increases the price of the machine. Operators, however, will be prepared to accept higher investments because their aim is to lower operating costs over the long term.

That is why the time is right for machine builders and operators of thermoforming machines to rethink how they work in order to be successful in the future.

Luggage racks and trim parts in the aircraft interior are produced in the thermoforming process on sheet-fed machines. The same applies to hard-shell cases.

Sources

Schwarzmann 2016: p. 1, 6	Peter Schwarzmann, Thermoformen in der Praxis [Thermoforming in Practice], 3. Edition 2016, Hanser Verlag, Munich, Germany
Bauer et al. 1998: p. 330	Bauer, Brinkmann, Osswald, Rudolph und Schmachtenberg, Saechtling Kunststoff-Taschenbuch [Plastics Pocketbook], 27th Edition 1998, Hanser Verlag, Munich, Germany
Kaiser 2006: p. 193	Wolfgang Kaiser, Kunststoffchemie für Ingenieure [Plastics Chemistry for Engineers], 1. Edition 2006, Hanser Verlag, Munich, Germany
Leupen et al. 1989: p. 199	A. Leupen, H. Vetsch, F. K. Kneubühl, Investigation, Comparison and Improvement of Technical Infrared Radiators, released 1989, Infrared Physics Laboratory, ETH Zurich, Switzerland

Contact

Oliver Hinz
Senior Product Manager IH
Leister Technologies AG

+41 41 662 74 17
oliver.hinz@leister.com

Silvio Conti
Manager Technology Infrared
Leister Technologies AG

+41 41 662 87 02
silvio.conti@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

Legal Notices

Contents

We have carefully prepared the content of this white paper.
We do not make any guarantee of any kind for the information.
We reserve the right, without further notice, to change or update all information provided at any time.

Copyright | Industrial Property Rights

Texts, images, graphics and their arrangement are subject to copyright protection and other protective laws.
The reproduction, modification, transfer or publication of part or all of the contents of this white paper is prohibited in any form, except for private, non-commercial purposes.

All marks contained in this white paper (protected trademarks, such as logos and business names) are the property of Leister Technologies AG, Leister Brands AG or third parties and may not be used, copied or distributed without prior written consent.

Modifications

Modifications can be made at any time.

© Leister Technologies AG
Galileo-Strasse 10
6056 Kaegiswil
Switzerland

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

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