English version

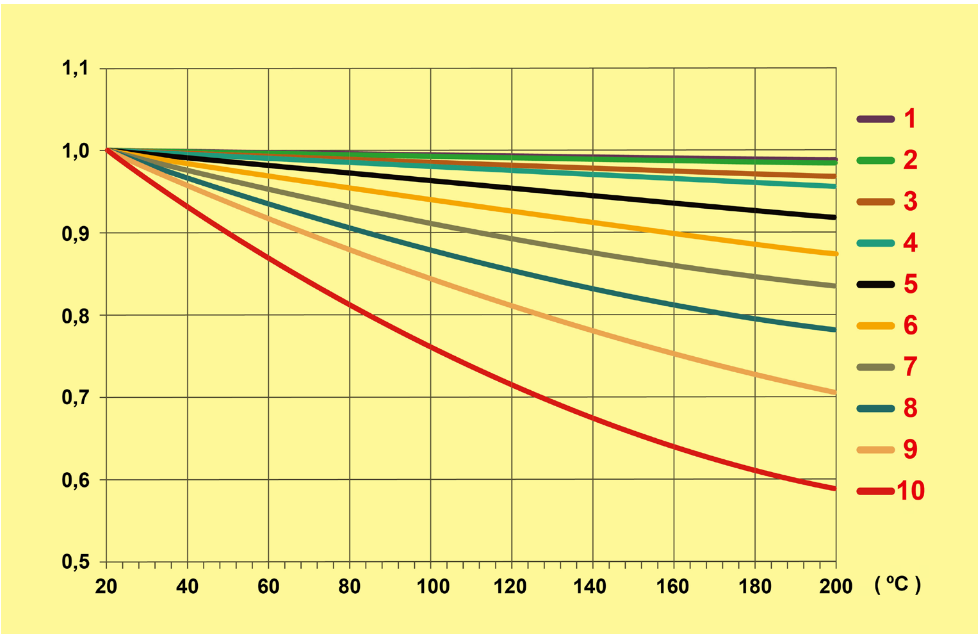
ULTIMHEAT® MUSEUM

Jacques Jumeau

Technology of components used in heating.

Chapter 47

Technical introduction to Silicone heaters



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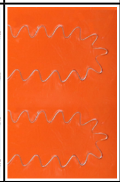
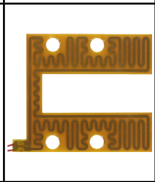
With the arrival on the market of many manufacturers and the spread of sales by internet without any technical specifications, popped up many products, most of time simple visual copies, without any technical validation, and the purchase of which is made most often in view of pictures and of a price. With this technical introduction, we want to show that our continuous search for improvements and superior technology is the only way to provide our professional customers with reliable and sustainable solutions, taking into account the multiple technical pitfalls of flexible silicone elements. Nothing in the design of our devices was left to chance or approximation. Unless otherwise specified, all tests were performed in Ultimheat laboratory.

Ultimheat is ISO 9000-2015 and ISO 14000-2015 certified (the last existing versions). It is also a government Certified High Technology Company.

Technical introduction summary

1: Comparison of flexible heaters main technologies*

	Heating fabrics	Silicone rubber heaters			Thin insulation foils heaters	
Type	1 **Wire wound heating element embedded in fabric**	2 **Zig-Zag heating wires**	3 **Wire wound heating element vulcanized inside rubber**	4 **Etched metal foil vulcanized inside rubber**	5 **Thick film heaters, silk screen printed**	6 **Etched foil bonded on insulating film**
Picture						
Temperature range	-20+120°C . Usual value as it depends of the fabric used and heating wire insulation. (From -20+120°C for PA66 to -60+350°C for fiberglass or aramide)	-60°C to 230°C.	-60°C to 230°C.	-60°C to 230°C.	-20+80°C. Temperature resistance depends mainly of conductive and resistive inks used. Insulation foil can be PVC or PET or even polyimide. Surface power load limited to 0.2W/cm².	-60 to 230°C. Usual value, as it depends of insulation foil material, adhesive used to bond the foils. Insulation film can be PET (max 120°C due to film material), Kapton (max 230°C due to PSA)
Flexibility	Good resistance to bending and repeated flexing.	Limited resistance to bending and repeated flexing.	The best resistance to repeated flexing.	Limited to static application because poor resistance to flexion of the metal foil.	Very poor resistance of inks to flexion.	Limited to static application because poor resistance to flexion of the metal foil.
Used in	Industrial jacket heaters. Domestic and industrial blanket heaters and heating pads. Heating clothes.	Industrial flexible silicone heaters. Low volume applications.	Industrial flexible silicone heaters, low volume applications	Most of large volume industrial and commercial applications requesting high temperature resistance and high watt/cm²	Low cost and low temperature heaters used in automobile for heating seats or mirrors to keep ice from forming on the side view mirrors of cars, busses and trucks.	Applications that require a lightweight solution or a rapid heat-up time. Wide temperature range when using Kapton

	Heating fabrics	Silicone rubber heaters			Thin insulation foils heaters	
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Technology	The oldest technology, dating back to the end of 19th century. The resistive conductor is coiled around fiberglass or aramid core. (It was asbestos until 50 years ago). Then the flat heater can be made using 2 technical solutions: 1/- Heating fabric whose warp yarns are made of fiberglass, cotton aramid, polyimide, and weft yarns are made of this coiled heating wires 2/-Stitching the wires on a fabric. This solution allows to use wires with a primary insulation in silicone or FEP. Then the primary insulation can receive a metal braid, for grounding. This is the single way to produce flexible heaters with a grounding braid, requested in some industrial applications.	The resistive conductor is formed in a flat zig-zag, and assembled in a web. This technology produces heaters without thickness increase, similar to the etched models. The cheapest solution for small quantities, (Technology patented by Ultimheat)	The resistive conductor is coiled around fiberglass or polyimide core. Then a web is made with the coiled wires hand pressed on the un-vulcanized silicone. Then the heating web is vulcanized between 2 sheets of fiberglass reinforced silicone rubber. In their traditional time-consuming assembly process, they are only suited for small quantities. In the Ultimheat patented technology the fiberglass fabric net and the heating wire are computer designed, and heating wire is automatically embedded in the fiberglass net before vulcanizing. This allows fully automated production and large volume applications.	The heating element conductive web is made from a thin metal sheet chemically etched with a technology similar to the printed circuits processing. Then this metallic web can be vulcanized between 2 flexible and insulating sheets. Sheets can be made of any type of rubber or elastomers. Because of the larger paths, smaller spacing between elements and better heat transfer, the power density can be up to 2 time bigger than classical wire wound models. They are suited for medium and large quantities.	Thick film heaters are constructed on silk screening of conductive and resistive inks. These inks are printed on a flexible substrate. They can be produced using an ink that makes the heater capable of self-regulating its temperature or as a fixed resistance heater.	Etched foil Kapton flexible heaters are made with a thin metal foil as the resistance element. The resistance pattern is designed in CAD and transferred to the foil in a process similar to the printed circuits manufacturing. The metal foil is then laminated and bonded to the insulating substrate with adhesive (FEP or Acrylic). The metal foil/ substrate is then processed through an acid to produce the etched heating element. The top layer is then added and bonded and laminated with adhesive as done for the first side. Polyimide heater offers dimensional stability and high tensile strength. It is also resistant to most chemicals. (Kapton is a brand name from Dupont for polyimide).

* Types 1, 2, 3, 4 are produced by Ultimheat.

2-Drums reheating

2-1. Standardized dimensions of drums

One of the most common applications of flexible silicone heaters is reheating drums. It is therefore necessary to specify the theoretical and practical dimensions.

The most common, the 200-litre drum (known as a 55-gallon drum in the United States and a 44-gallon drum in the United Kingdom) is a cylindrical container with a nominal capacity of 200 litres (55 US or 44 imp gal). The exact capacity may vary by manufacturer, purpose, or other factors. Standard drums have inside dimensions of 572 millimetres (22.5 in) diameter and 851 millimetres (33.5 in) height inside. These dimensions yield a volume of about 218.7 litres (57.8 US gallon; 48.1 Imperial gallon), but they are commonly filled to about 200 litres.

The outside dimensions of a 200-litre drum are typically 584 millimetres (23 in) diameter at the top or bottom rim, 597 millimetres (23.5 in) diameter at the chines (ridges around drum), and 876 millimetres (34.5 in) height.

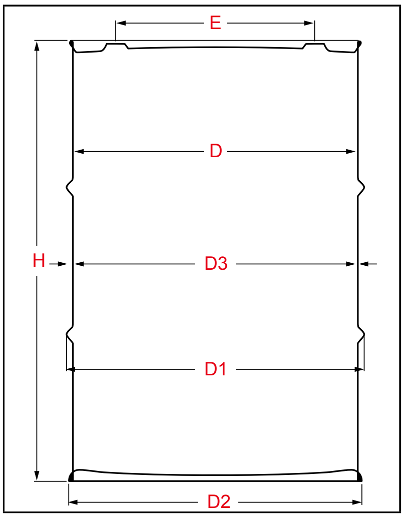
The external dimensions are identical to a few millimeters in the US and ISO versions. The nominal diameters of the threads of the bungs on the top cover are identical, but differ in the pitch used:

According to the American standard ANSI MH2, the threads are of type NPT.

According to the international standard ISO 15750 the threads are type G2 "and G¾" (ISO 228-1 standard)

This arrangement is echoed in many plastic drums in the same size. Various components can be mounted to the drum, such as drum pumps and bung mixers.

Usual dimensions of steel drums



Capacity Liters (US gallons)	Overall height H mm ± 6.4 (in inches ± 1/4)	Inside diameter D in mm ± 3.2 (in inches ± 1/8)	Over-hoop diameter D1 in mm ± 3.2 (in inches ± 1/8)	Over-chime diameter D2 in mm ± 3.2 (in inches ± 1/8	Outside diameter at no hoop D3 in mm ± 3.2 (in inches ± 1/8)	Distance between fittings centers E in mm (inches)	N° of hoops
19-20 (5)	283 (11-1/8)	356 (14)	371 (14-5/8)	363 (14-5/16)	359 (14-1/8)	210 (8-1/4)	2
30 (8)	412 (16-1/4)	356 (14)	371 (14-5/8)	363 (14-5/16)	359 (14-1/8)	210 (8-1/4)	2
38 (10)	489 (19-1/4)	356 (14)	371 (14-5/8)	363 (14-5/16)	359 (14-1/8)	210 (8-1/4)	2
60 (16)	733 (28-7/8)	356 (14)	371 (14-5/8)	363 (14-5/16)	359 (14-1/8)	210 (8-1/4)	2
75 (20)	552 (21-3/4)	463 (18-1/4)	486 (19-1/8)	475 (18-11/16)	466 (18-3/8)	343 (13-1/2)	2
110/120(30)	749 (29-1/2)	463 (18-1/4)	486 (19-1/8)	475 (18-11/16)	466 (18-3/8)	343 (13-1/2)	2
200/220 (55)	878 (34-1/2)	572 (22-1/2)	593 (23-3/8)	586 (23-1/16)	574 (22-5/8)	444 (17-1/2)	2
For silicone heating belts, the diameter D3 must be taken into account. Under no circumstances should the heating belt be applied to diameters D1 or D2							

2-2. Drums reheating with flexible silicone belts

Reheating time of drums
This is the most common question: How long will it take to heat a drum?
A first approach must take into account a number of critical parameters, and the main ones are:

1-The total volume heated.
For a given power a large volume will heat up less quickly than a small volume

2-The total power applied.
Higher power will in principle warm up faster

3-The distribution of power.
Heating distributed over the whole mass or on all the walls will heat up faster than heating located on a small surface of the tank

4-The thermal conductivity of the liquid.
The higher the thermal conductivity of the liquid, the faster the heat is transmitted to the whole mass

5-The heat capacity of the liquid.
Since the heat capacity represents the energy that must be applied to a mass of liquid to heat it, liquids with a low heat capacity will heat, at equal power, faster than those with a high heat capacity.

6-The kinematic viscosity (ν) of the liquid.
The more viscous a liquid, the fewer convection currents. So the heat energy is transmitted less quickly. It may be necessary in some cases to add a mixing apparatus for viscous, low-conductive products.

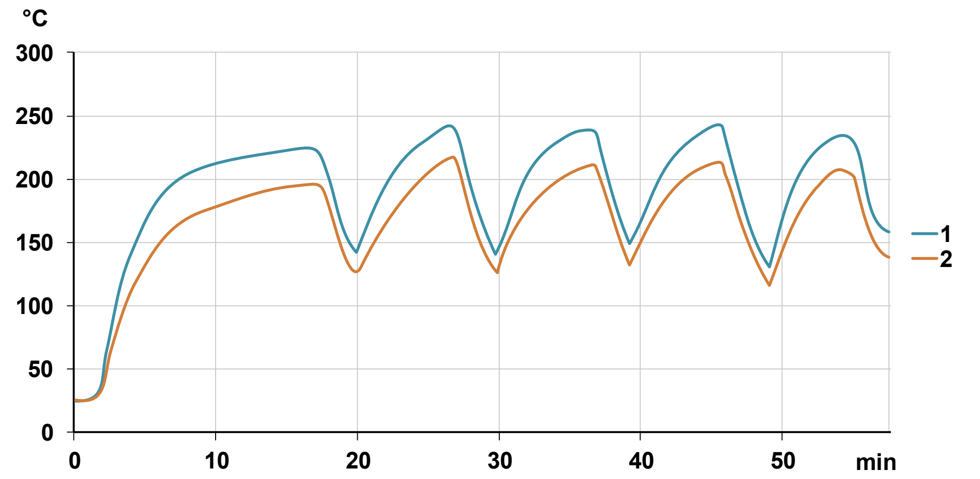
7-The thermal insulation.
By eliminating heat losses to the outside, the heat energy is concentrated on the tank. An insulated tank will heat up faster. Insulating jackets are available for all dimensions of drums

8-The type of action of temperature control.
PID-type temperature control reduces the power supplied to the tank nearby the set point, therefore the heating time is increased but the usual overheating of on/off control systems is avoided. Improper positioning of the temperature measuring point, for example in the middle of the heated liquid, increases the risk of overheating of the walls, due to the time taken by the heat energy to reach this central location.

9- Thermal safety devices.
When thermal safeties are installed in the heating systems, they limit the temperature reached by the heating element to prevent its destruction by overheating. This limitation can increase the duration of the heating, in particular when the thermal exchanges with the liquid are bad, because of its thermal conductivity or its viscosity.

10-The heating surface.
Silicone belt heaters only cover a small part of the surface of the tanks. The heating is done by thermal conduction between this small surface and the heated product, and the temperature homogeneity is long to be done. So, every-time it is possible, the silicone heater surface should be increased to the maximum.

Overheat of flexible silicone heating belts mounted on empty drums
We strongly discourage this use, as the wall temperatures reached are almost always higher than the silicone belt destruction temperature. If, despite all, this can happens in the application, we recommend the use of a surface temperature control system (eg limiter at 190°C), in addition to the electronic or mechanical thermostat control, and a limitation of the surface power density at 0.75W / cm²

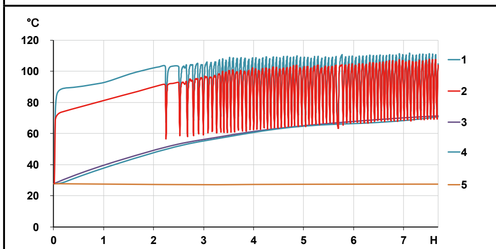


Temperature measurement made on a 200mm width silicone belt mounted on a 55 gallons (200 liters) drum. Power 2250W (0.75W/cm²), PID controller with sensor located in the center of the empty tank. Surface temperature limited to 190°C by a disc thermostat.
1: Temperature of the inner wall of the heating belt
2: Temperature of the outer wall of the heating belt.
Despite the action of the temperature limiter, the surface temperature varies between 220 and 240°C, so it is potentially destructive. The electronic temperature controller temperature sensor being located inside the empty barrel, it does not measure the temperature rise of the wall, and its regulating action does not occur.

Comparative practical examples of reheating drums with flexible silicone heating belts

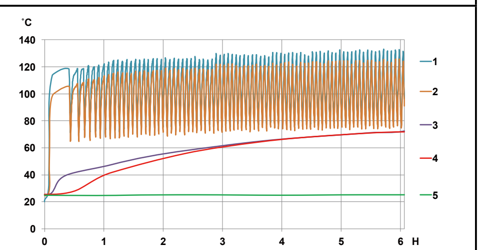
Temperature control by mechanical bulb and capillary thermostat mounted on the surface. The set point of 90°C has been selected to avoid bringing water to boiling point. (Without surface temperature limiter)

Variation in the temperature versus time of a 220-liter metal drum, filled with water, heated by a silicone heating belt 200mm wide, without thermal insulation, power 2250W (surface load 0.75W/cm²).



1: Surface temperature between silicone belt and drum
2: Outside silicone belt surface temperature
3: Water temperature, at diameter center, at 50mm from the top
4: Water temperature, at diameter center, at, half height of the drum
5: Water temperature, at diameter center, at 50mm from the bottom

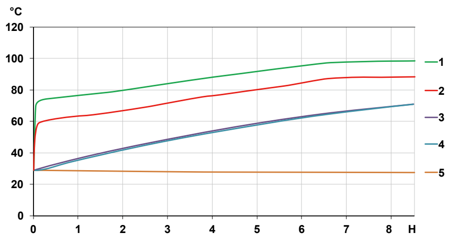
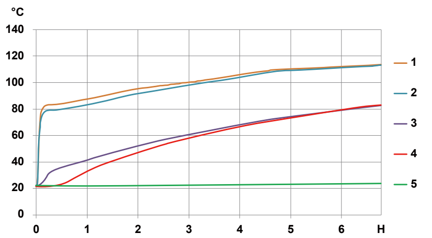
Variation in the temperature versus time of a 220-liter metal drum, filled with HF 24-6 hydraulic oil, heated by a silicone heating belt 200mm wide, without thermal insulation, power 2250W (surface power load 0.75W/cm²).



1: Surface temperature between silicone belt and drum
2: Outside silicone belt surface temperature
3: Oil temperature, at diameter center, at 50mm from the top
4: Oil temperature, at diameter center, at, half height of the drum
5: Oil temperature, at diameter center, at 50mm from the bottom

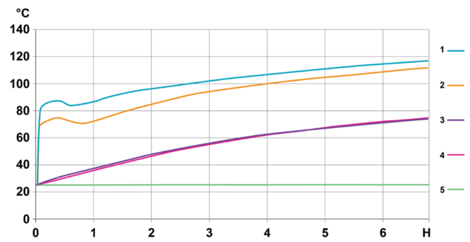
Analysis of the results: It is noted in these tests that the temperature difference between the middle and the top of the tank is almost zero. The bottom of the tank does not heat up. The heating time is 7:30 minutes before the temperature of the liquid at the level of the heating belt reaches 70°C. Operation of the thermostat set at 90°C results in wide temperature oscillations at the heating belt walls Energy efficiency is very low (35%) compared to insulated heating coats that can reach 85 to 90%.	**Analysis of the results:** It is noted in these tests that the temperature difference between the middle and the top of the tank is quickly becoming null. The bottom of the tank does not heat up. The heating time is 5 hours before the temperature of the liquid at the level of the heating belt reaches 70°C. Operation of the thermostat set at 90°C results in wide temperature oscillations rising up to 130°C at the heating belt walls Energy efficiency is very low (32%) compared to insulated heating coats that can reach 85 to 90%.

Heating with electronic remote control, by PID controller, set point set to 90°C, Pt100 sensor mounted on the surface of the heating belt. (Without surface temperature limiter)

Variation in the temperature versus time of a 220-liter metal drum, filled with water, heated by a silicone heating belt 200mm wide, without thermal insulation, power 1500W (surface load 0.5W/cm²).	**Variation in the temperature versus time of a 220-liter metal drum, filled with HF 24-6 hydraulic oil, heated by a silicone heating belt 200mm wide, without thermal insulation, power 1500W (surface power load 0.5W/cm²).**
	
1: Surface temperature between silicone belt and drum 2: Outside silicone belt surface temperature 3: Water temperature, at diameter center, at 50mm from the top 4: Water temperature, at diameter center, at half height of the drum 5: Water temperature, at diameter center, at 50mm from the bottom	1: Surface temperature between silicone belt and drum 2: Outside silicone belt surface temperature 3: Oil temperature, at diameter center, at 50mm from the top 4: Oil temperature, at diameter center, at, half height of the drum 5: Oil temperature, at diameter center, at 50mm from the bottom
Analysis of the results: It is noted in these tests that the temperature difference between the middle and the top of the tank is almost zero. The bottom of the tank does not heat up. The heating time is 8:30 minutes before the temperature of the liquid at the level of the heating belt reaches 70°C. Energy efficiency is very low (30%) compared to insulated heating coats that can reach 85 to 90%	**Analysis of the results:** It is noted in these tests that the temperature difference between the middle and the top of the tank is almost zero. The bottom of the tank does not heat up. The heating time is 4:30 minutes before the temperature of the liquid at the level of the heating belt reaches 70°C. This is only 55% of the time used to heat water in the same conditions. Energy efficiency is very low (30%) compared to insulated jacket heaters that can reach 85 to 90%

Heating with electronic remote control, PID action regulator, Pt100 sensor immersed in the center of the tank, surface temperature of the heating belt protected by a bimetal disc temperature limiter set at 190°C to prevent destruction of the heating element by overheating.

Variation in the temperature versus time of a 220-liter metal drum, filled with water, heated by a silicone heating belt 200mm wide, without thermal insulation, power 2250W (surface load 0.75W/cm²).

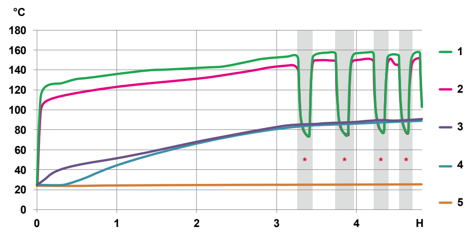


1: Surface temperature between silicone belt and drum
2: Outside silicone belt surface temperature
3: Water temperature, at diameter center, at 50mm from the top
4: Water temperature, at diameter center, at, half height of the drum
5: Water temperature, at diameter center, at 50mm from the bottom

Analysis of the results: It is noted in these tests that the temperature difference between the middle and the top of the tank are very quickly identical, while the bottom of the tank is absolutely not warmed. The heating time is 6 hours 30 minutes for the temperature of the liquid at the level of the heating belt reaches 70°C.

Energy efficiency is very low (35%) compared to insulated heating coats that can reach 85 to 90%

Variation in the temperature versus time of a 220-liter metal drum, filled with HF 24-6 hydraulic oil, heated by a silicone heating belt 200mm wide, without thermal insulation, power 2250W (surface power load 0.75W/cm²).



1: Surface temperature between silicone belt and drum
2: Outside silicone belt surface temperature
3: Oil temperature, at diameter center, at 50mm from the top
4: Oil temperature, at diameter center, at, half height of the drum
5: Oil temperature, at diameter center, at 50mm from the bottom

Analysis of the results: It is noted in these tests that the temperature difference between the middle and the top of the tank are very quickly identical, while the bottom of the tank is absolutely not warmed. It takes 2h30 minutes for the temperature of the liquid at the level of the heating belt to reach 70°C.

Compared with the heating of the water under the same conditions, the time saving is important (ratio of 0.4)

But the surface temperature of the heating element reaches the limit of 190°C because of the low thermal conductivity of the oil and its lower heat capacity. The surface temperature limiter is essential (The zones * are the periods when the limiter has cut off the supply of the heating element).

Energy efficiency is very low (25%) compared to insulated jacket heaters that can reach 85 to 90%.

Comparison of heating times required for different liquids currently heated by silicone belt heaters.

In order to give an idea to the users heating specific products, we carried out, under identical test conditions, comparative tests by recording the necessary time and the evolution of the temperature during the heating of a liter of product, from 20 °C to 90 °C (measured at the geometric center of the tank).

These tests were made with two different values of surface power load: 0.1W/cm² and 0.4W/cm².

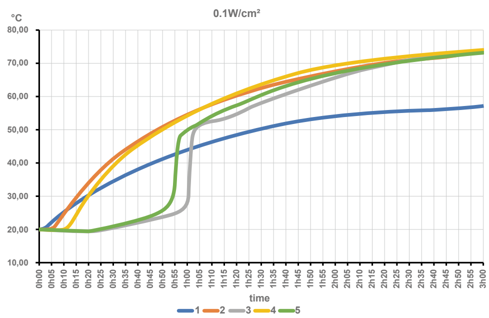
Test conditions: Heating performed in a cylindrical tank diameter 76 mm height 280 mm, flat bottom, red copper 2 mm thick, the entire cylindrical portion filled with the product (250 mm) is heated by a flexible silicone heater, insulated with 20mm of PVC-NBR foam. The heating is made without temperature control or safety temperature limiter. The ambient temperature is maintained at 20 °C. in a climatic chamber. The test is stopped when the temperature at the center of the product has reached 90 °C.

Testing equipment

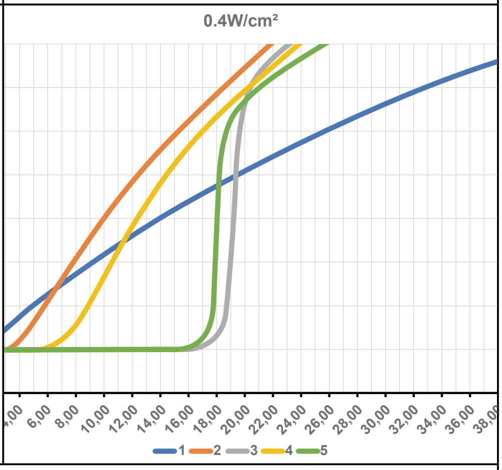
Characteristics of the products used in the tests

Products	Thermal conductivity W/m.K	Specific heat capacity (kJ/kg.K)	Kinematic viscosity at 20 °C mm²/s	Specific gravity Kg/m3
Water	0.597@20°C	4.182	1.006@20°C	0.998@20°C
Olive oil	0.189@15°C	1.25	91.5@20°C	0.922 @20°C
Lard	0.407@25°C	2.1	Frozen (melting between 35 and 42 °C)	0.924-0.930
Mineral oil ISO VG680	0.134@40°C	1.99	4000@20°C	0.850
Butter	0.197 @46°C	2.3	Frozen (melting between 27 and 32 °C)	0.87-0.93

With a surface load of 0.1W/cm² (60W)



With a surface load of 0.4W/cm² (240W)



1: Water 2: Olive oil 3: Lard 4: ISO VG680 Mineral oil 5 : Butter

Analysis of the results: The water, with a heating capacity of 2 to 4 times greater than the other products, thus requires more energy to warm up and thus heats up much less quickly. Products frozen at room temperature (butter, animal fat) retain for a long time a central cold part for lack of convection currents, before quickly reaching the temperature of the other oils when they liquefy.

3- Pipes heating

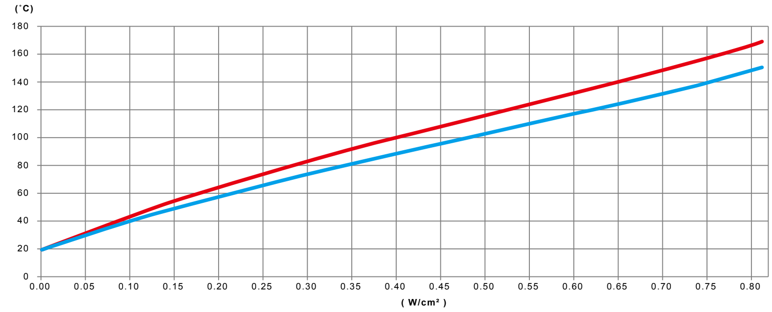
3-1 Pipes surface temperature

A second application of flexible silicone heaters is heating or antifreeze protection of the pipes. The temperature reached on the pipe surface is the most important parameter. We have therefore performed a number of tests to allow users to have benchmarks before selecting a flexible silicone heater for these applications.

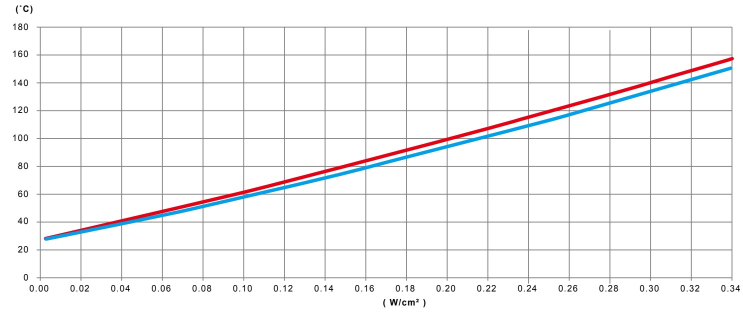
Condition of the comparative tests: Silicone heating ribbons wound on tubes of external diameter 25mm, in PVC-U, galvanized steel and stainless steel

In order to characterize the power requirements, comparative tests under different conditions have been carried out. The heating was carried out by a flexible silicone ribbon wounded on the tube with a pitch equal to twice its width, thus covering half of the surface of the tube. The power in W/cm² provided in the test results is that of the heating tape. It must therefore be divided by 2 to relate it to the surface of the tube. In blue the wall temperature of the tube outside areas covered by the heating tape. In red the wall temperature of the tube in the areas covered by the heating tape. Measurement was made at an ambient temperature of 25°C.

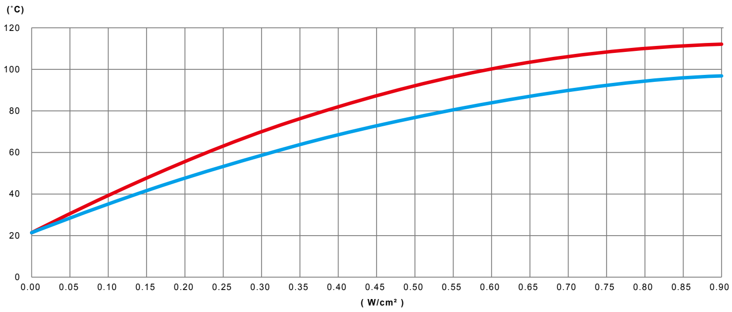
Test results on stainless steel tubes



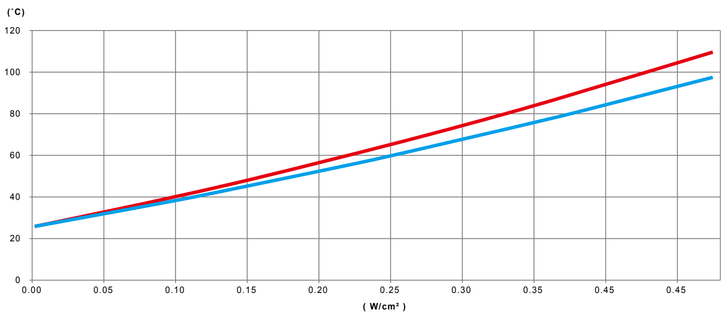
Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of an empty, non-thermally insulated stainless steel tube



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of an empty stainless-steel tube, thermally insulated by 20mm of PVC-NBR foam



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of a stainless-steel tube, filled with non-circulated water, no-thermally insulated



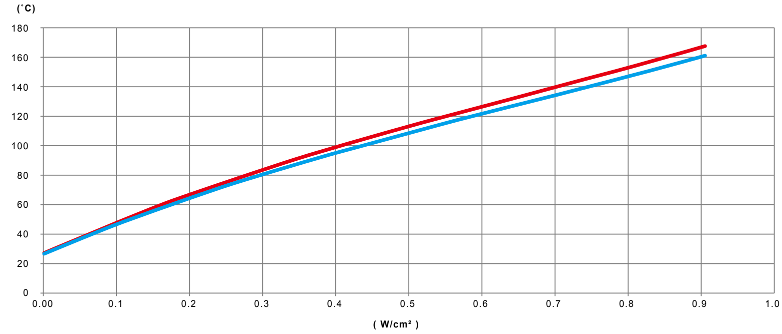
Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of a stainless-steel tube, filled with non-circulated water, thermally insulated by 20mm of PVC-NBR foam

Results analysis:

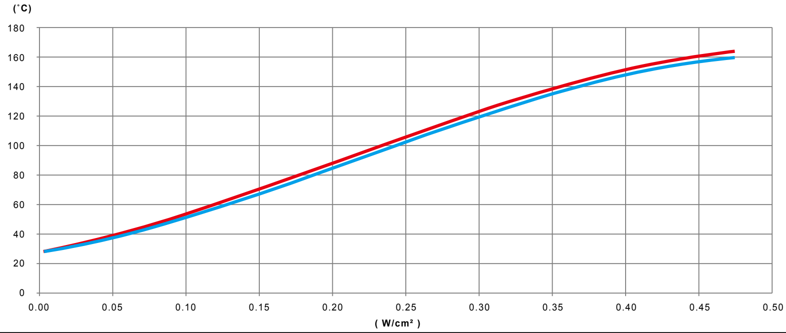
- Homogeneity of temperature: the stainless-steel tubes being rather bad heat conductors, one notices strong differences of temperature between the heated zones and the not heated zones, in particular for empty tubes This difference is attenuated during the use of insulated tubes.

- Recommended power: For uninsulated stainless-steel pipes with non-circulating water, such as domestic water supply pipes, a value of 0.42 W/cm² is sufficient to protect against freezing up to -20°C. For insulated tubes, this value is 0.3 w/cm²

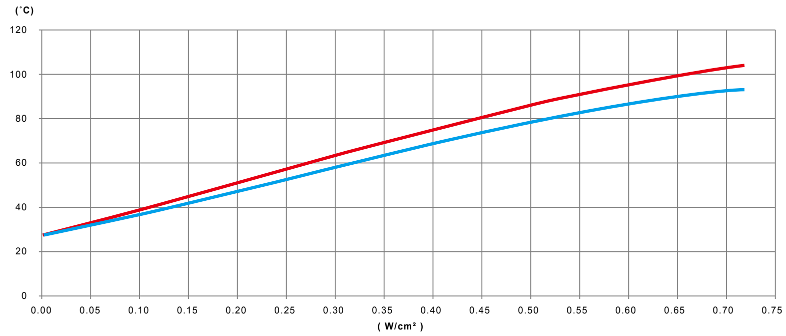
Test results on galvanized steel tubes



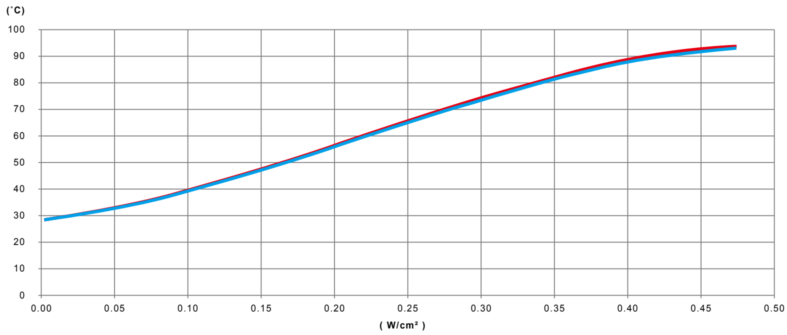
Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of an empty, non-thermally insulated galvanized steel tube



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of an empty, galvanized steel tube, thermally insulated by 20mm PVC-NBR foam



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of a galvanized steel tube filled with non-circulating water, non-thermally insulated



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of a galvanized steel tube filled with non-circulating water, thermally insulated by 20mm PVC-NBR foam

Results analysis:

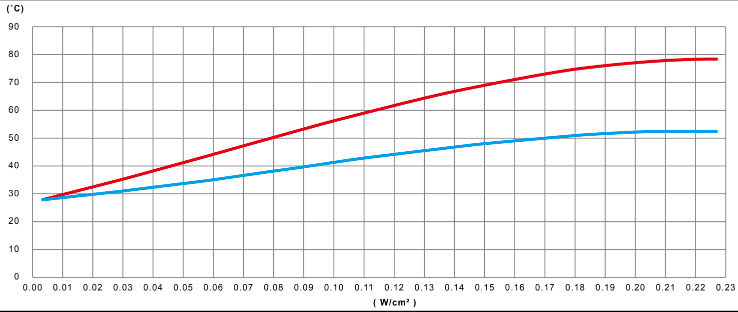
- Homogeneity of temperature: The steel tubes being fairly good heat conductors, we note a good homogeneity of temperature between the heated zones and the unheated zones, the two becoming almost identical in the isolated tubes.

- Recommended power: For non-insulated steel pipes with mostly non-circulating water, such as domestic water supply pipes, a value of 0.4 W/cm² is sufficient to protect against freezing up to -20°C. For insulated tubes, this value is 0.27 W/cm²

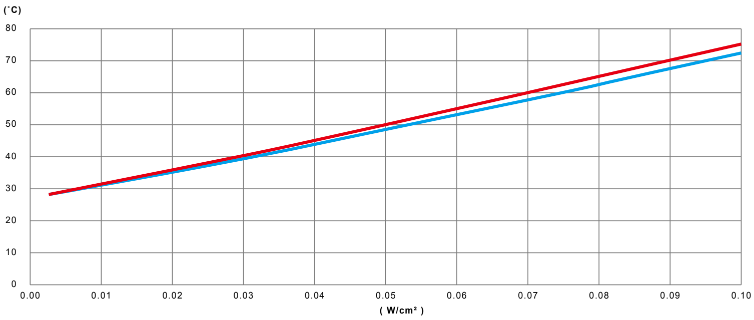
Test results on U-PVC tubes

The heating of the plastic pipes is limited by their softening temperature.

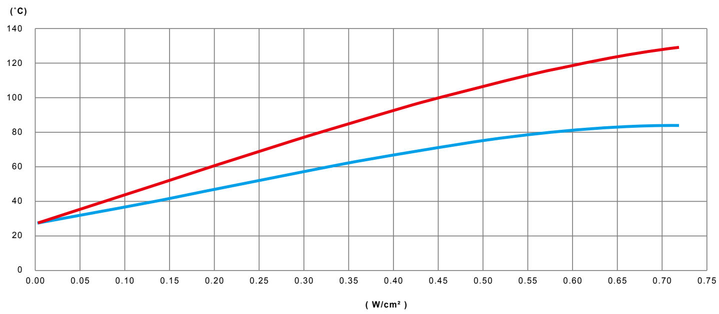
It is important to note that if the PVC tube is likely to be empty during the warm-up period, the temperature under the silicone heater ribbon must remain below this softening temperature, which is between 80 and 100°C depending of the type of PVC. (PVC, U-PVC, C-PVC).



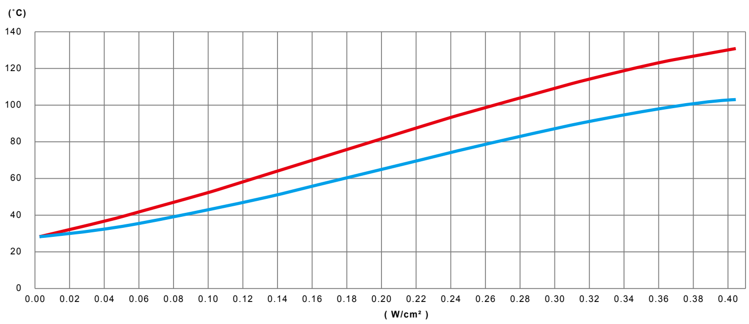
Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of an empty, non-thermally insulated PVC tube



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of an empty PVC tube, thermally insulated by 20mm of PVC-NBR foam



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of a PVC tube filled with non-circulating water, non-thermally insulated



Variation, as a function of the power in W/cm² of the silicone heating ribbon, of the wall temperature of a PVC tube filled with non-circulating water, thermally insulated by 20mm PVC-NBR foam

Results analysis:

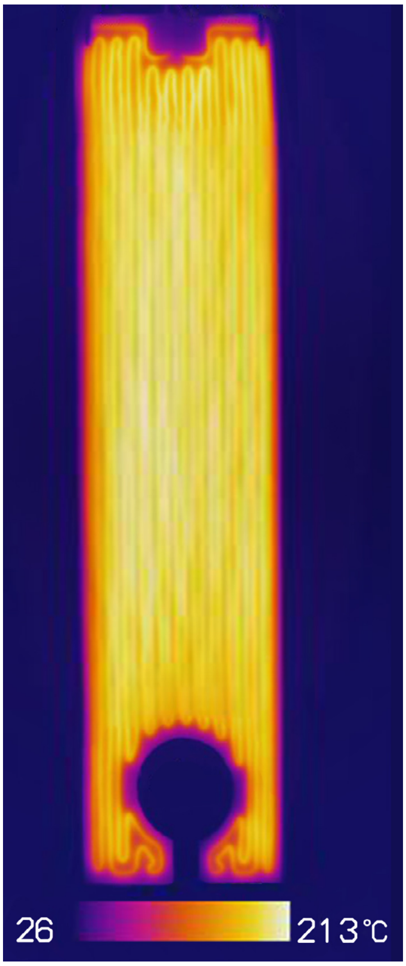
- **Homogeneity of temperature:** PVC pipes being poor heat conductors, there is a very large difference in temperature between the heated zones and the unheated zones, which weakens in the insulated tubes but still reaches more than 20°C.
- **Recommended power:** For PVC or U-PVC pipes insulated with non-circulating water, such as domestic water supply pipes, a value of 0.45 W/cm² is sufficient to protect against frost up to -20°C. For insulated tubes, this value is 0.22 W/cm².

4-Boards heating with flexible silicone heaters

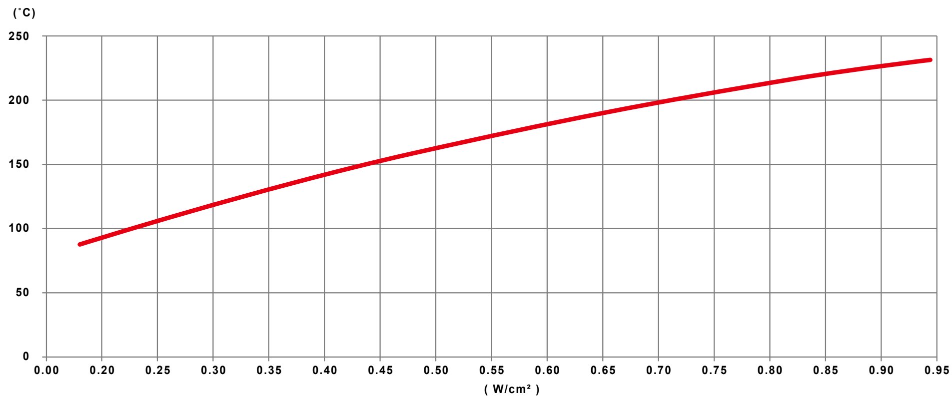
4-1. Surface temperature of boards as a function of the surface power

Depending on the surface power in W/cm², the temperature of a heated board will stabilize at different values. This temperature, will vary according to the level of its thermal exchanges with its environment. (In calm air, in ventilated air, in contact with boards made of different metals or plastics). The tests below intend to provide a general idea of the evolution of this temperature. (Non-contact measurements made by thermography).

Measurement on flexible silicone heater suspended in air

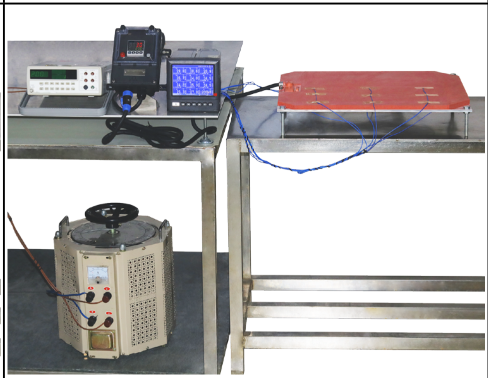
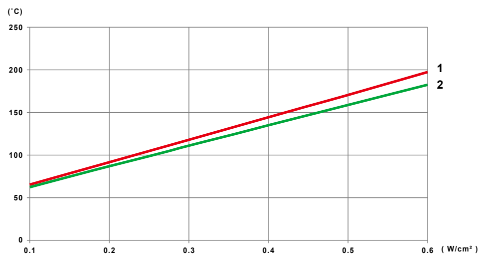
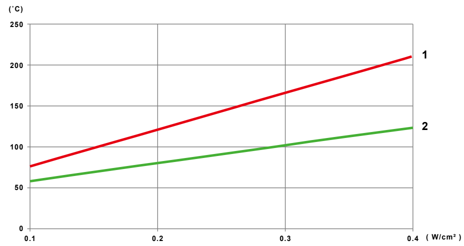


Thermographic image of a 2.4 mm flat silicone heater with a 1W/cm² surface power load, suspended in calm air, not fixed on a board, at an ambient temperature of 25°C. The surface temperature reaches 213°C, nearby its destruction.



Variation of the surface temperature of a 2.5mm thick silicone heater versus the surface power load. The heater is suspended in calm air, not fixed on a metal surface, at an ambient temperature of 25°C. The heater is not protected by a temperature limitation system. In these conditions, the heater is irreversibly damaged at 235°C.

Measurement on flexible silicone heaters mounted on non-immersed metal walls

<table>
<tr><th>Without thermal insulation</th><th>With 10mm silicone foam thermal insulation</th></tr>
<tr><td></td><td></td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>1: Average surface temperature of the aluminium plate
2: Averag temperature of the outside surface of the silicone heater.</td><td>1: Average surface temperature of the aluminium plate
2: Average temperature of the outside surface of the insulation foam.</td></tr>
<tr><td>Variation of the surface temperature versus the surface power load of a 2.5mm thickness silicone heater vulcanized on a flat 6mm thickness aluminum plate. The ambient temperature is 25°C. The aluminum plate reaches a surface temperature of 195°C for a 0.6W/cm² surface load density. The temperature difference between aluminium plate and outside surface of the silicone heater stays limited</td><td>Variation of the surface temperature versus the surface power load of a 2.5mm thickness silicone heater vulcanized on a flat 6mm thickness aluminum plate. A 10mm thickness silicone insulation foam is vulcanized on the silicone heater. The ambient temperature is 25°C. The aluminum plate reaches a surface temperature of 210°C for a 0.4W/cm² surface load density. Temperature difference between the 2 faces reaches 90°C at 0.4W/cm²</td></tr>
</table>

5- Constructional parameters of flexible silicone heaters

5-1. General parameters

The main characteristics of silicone heating resistors are: flexibility and the possibility to produce a high surface power density. The consequences of these characteristics have a major influence on the construction methods.

1- To obtain high heating powers, low electrical resistance heaters are required because the power is equal to U^2/R, so for a given voltage the resistance is inversely proportional to the power.

2- To maintain flexibility, the heating conductors must be of the smallest possible diameter, and arranged in a configuration that facilitates bending.

3- To obtain a good homogeneity of temperature, it is necessary to have the greatest length of wire per unit of surface.

4- To avoid hot spots and the destruction of the vulcanized silicone sheet around the heating wire, it is necessary that the surface power remains as low as possible so that its surface temperature remains below that supported by the silicone.

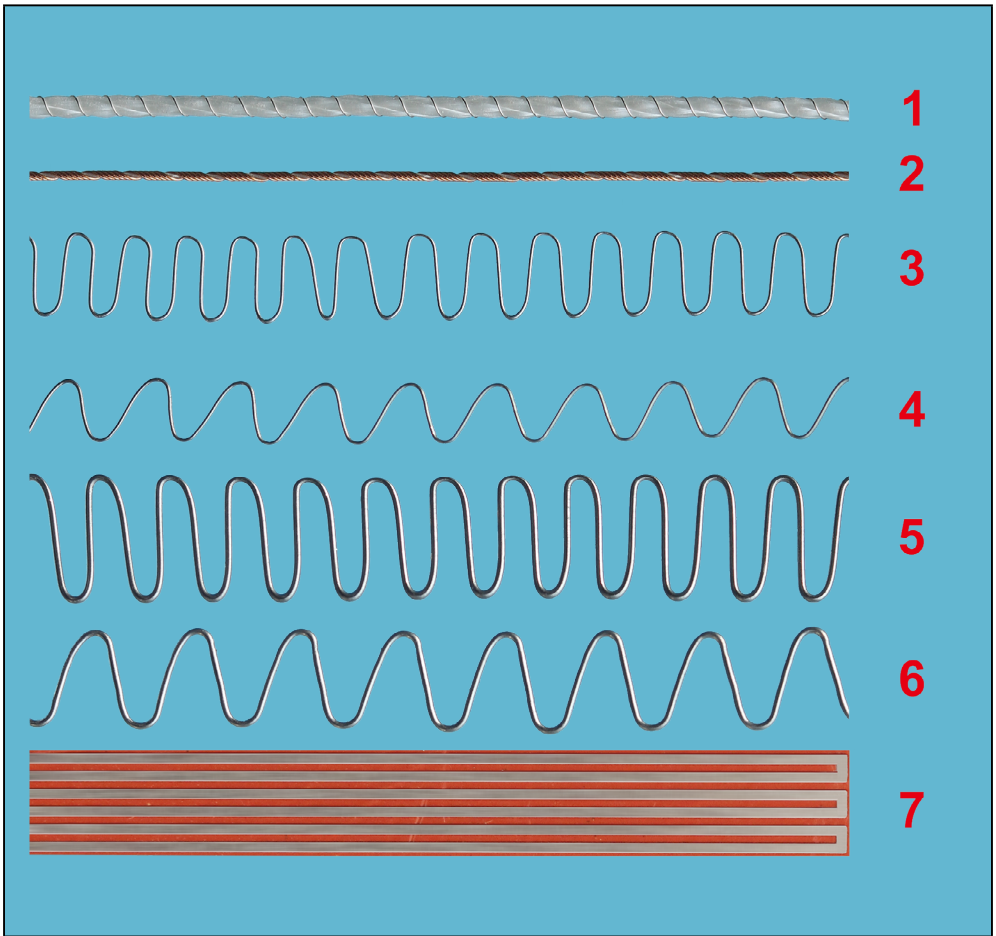
We see that these parameters 2, 3 and 4 are a priori incompatible with the parameter N°1, and that the manufacture of flexible heaters resistors of high power seems impossible. But the manufacturers of heating wires have mainly developed alloys with high resistivity to reduce the length required, as it is the most economical solution.

So the only remaining parameters that can be modified are:

- The wire forming technology (Small diameter coil around a fiberglass core, zig-zag flat spring, sinusoidal flat spring),
- The assembly of several circuits in parallel in order to divide the power per circuit,
- The selection of heating wires in special low resistivity alloys.

It is the combination of these technical solutions, studied on a case-by-case basis, which guarantees good flexibility and a good density of heating wires per unit area and therefore a good homogeneity of temperature without hot spots.

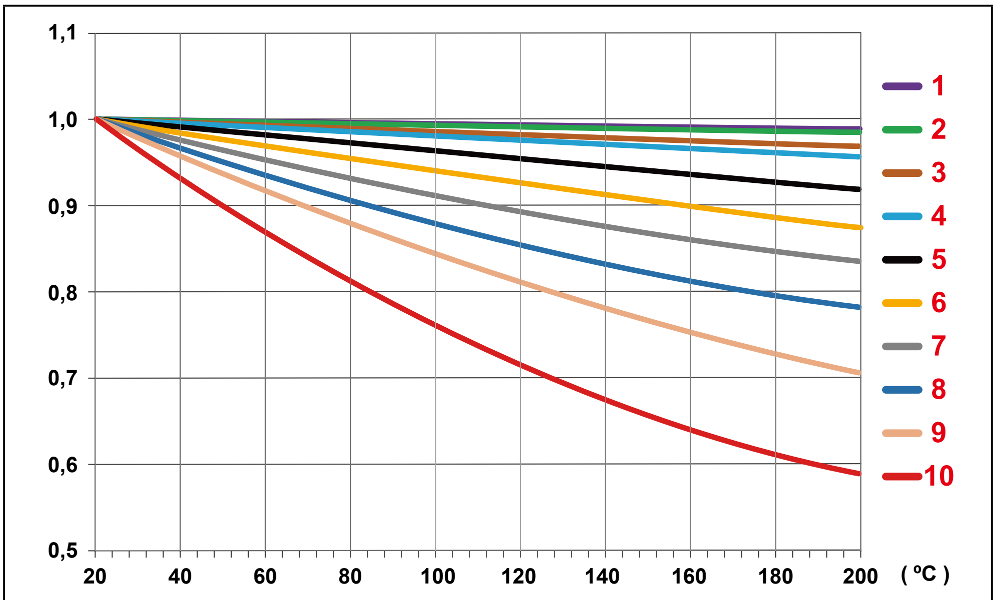
Some modern methods of forming heating wires for flexible silicone heaters



1: Wounded around a fiberglass core with 1 to 6 conductors in parallel; 2: Wounded around aramid core with 1 to 6 conductors in parallel; 3, 4, 5, 6: Flat zig-zag spring; 7: Heating net made by chemical etching of a metal foil.

5-2. The use of resistive wires with a positive temperature coefficient, null or negative, and consequently, the variation of the power as a function of the temperature.

A little-known parameter of flexible silicone heaters is the variation of their power when the temperature rises.
While in the high temperature heaters, manufacturers are looking for heating wires with a coefficient of variation of resistivity in temperature close to zero, and good performance without oxidation at high temperatures, using for example nickel-chromium alloys, in the flexible silicone heaters, the required temperature resistance is lower, as the maximum temperature of use is about 250°C.
This lower maximum temperature makes it possible to use a wider range of metals and alloys, with a range of resistivity values ranging from 0.017 to more than 0.50 Ohms. mm^2/m. This very wide resistivity range can be used to build heating elements of almost any surface, while remaining in flexible heating wire diameters. However, all of these alloys and metals have completely different temperature resistivity variation characteristics. It is therefore possible to use this parameter to produce heating elements that will self-regulate (or not) when the temperature rises.
For example, using alloy No. 9 in the table below, a heating element will see its power almost divided by 2 between 20 and 200 °C, while it will remain constant if alloy No. 1 is used.

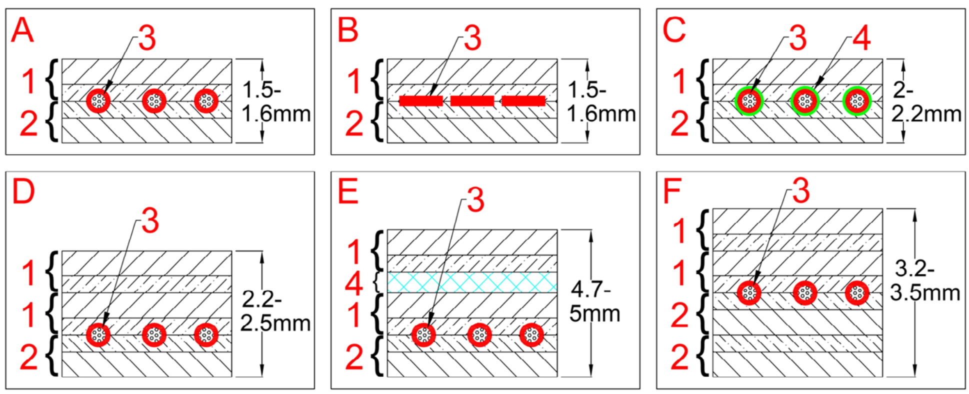


Coefficients of power variation of a heating wire as a function of temperature for some alloys and common metals.
1 : NiCr80-20 ; **2 : CuNi44 ; 3 : CuNi23 ;** 4 : CuNi10 ; **5 : CuNi6 ;** 6 : **304 ; 7 : CuNi2 : 8 : CuNi1 ; 9 : Cu ; 10 : Ni**

5-3. Design of the reinforced silicone sheets

The most important factor affecting the price of flexible silicone heaters is the weight of silicone per m^2. Silicone is an expensive raw material, and therefore the development of flexible heaters is based on the minimal use of this material.
The base is a fiberglass net that will be coated on each side with a layer of silicone resin, then polymerized by passing through a heating mill. The total silicone thickness is calculated to provide the electrical insulation (function of the operating voltage), and the fiberglass net to provide the mechanical strength, especially to the elongation.
Several layers can be vulcanized together to meet specific applications.
Flexible silicone heaters can be made in 6 main construction configurations:
A- In total thickness of 1.5 to 1.6mm, which corresponds to an insulating thickness of 0.75 to 0.8mm on both sides of the heating conductors. Made with coiled heating

wires, it provides the best resistance to bending. This solution is the most economical, especially for small series, but its mechanical strength is reduced by the small thickness. It is mainly used for heating elements of small surface, or intended to be glued. Having a low mass, it allows a faster temperature measurement by thermostats and temperature sensors mounted on its surface.
B- In total thickness of 1.5 to 1.6mm, which corresponds to an insulation thickness of 0.75 to 0.8mm on both sides of a heating network produced by chemical etching. This solution is the most economical for the production of large series, but the least resistant to bending. Having the lowest mass, the best heat distribution, it allows a faster temperature measurement of thermostats and temperature sensors mounted on its surface.
C- In total thickness from 2 to 2.2mm, which corresponds to an insulation thickness of 1 to 1.1mm on both sides of the heating conductors. This solution improves the electrical insulation towards the outside of the heating part because the use of heating conductors with a primary insulation in FEP confers the insulation class 2 to this assembly, without increasing its thickness too much. This solution is used in heating appliances subject to a regulation requiring an insulation class 2.
D- In total thickness of 2.4 to 2.5mm, which corresponds to an insulation thickness of 0.75 to 0.8mm on one side and 1.6mm on the other of the heating conductors. This solution improves the mechanical resistance and the electrical insulation towards the outside of the heating part. It is used for heating belts to be mounted and disassembled frequently, and large surface elements subjected to mechanical stresses
E- In total thickness of 2.5 to 2.6mm, which corresponds to an insulation thickness of 0.75 to 0.8mm on one side and 1.6mm on the other side of the heating conductors. In this thickness of 1.6mm is sandwiched a fine wire mesh of protection against punching and which also allows an efficient grounding. This solution improves electrical protection and resistance to elongation, but reduces flexibility.
A variant of this solution consists of using heating conductors comprising a primary electrical insulation covered with a metal braid.
F- In total thickness of 3.2 to 3.4 mm, which corresponds to an insulation thickness of 1.6 mm on both sides of the heating conductors. This solution provides the highest mechanical strength and double insulation heaters (Class 2), but this extra thickness between the heating conductors and the surface increases the heat transfer time and therefore the risk of overheating.

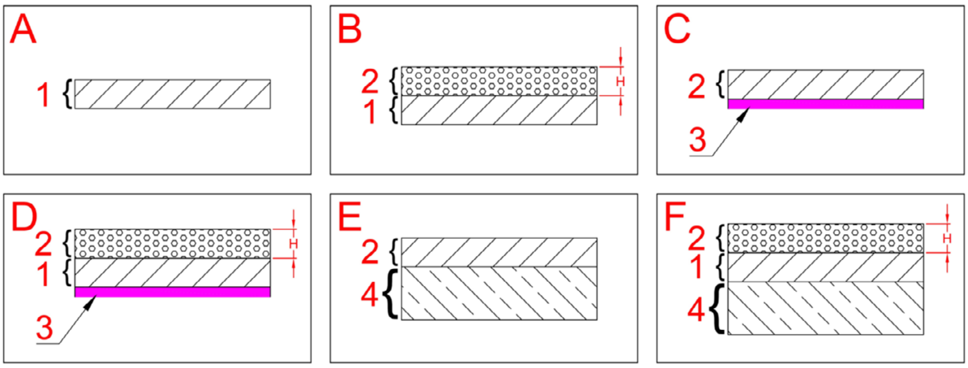


1: Fiberglass reinforced silicone compound of the upper face; 2: Fiberglass reinforced silicone compound of the lower face; 3: Heating wires; 4: Metal mesh wire for grounding and mechanical reinforcement; 5: FEP Primary insulation of heating wires.

5-4. Flexible silicone heaters surface coating

The flexible elements can receive equipment that is assembled on their surface, in order to meet different applications.
The main combinations are:
A: No equipment
B: One side with bonded or vulcanized silicone insulating foam, providing thermal insulation to the outside

C: One side with PSA type adhesive, usually of acrylic type, very thin, to stick the heating element on the wall to be heated. Adhesives can be used up to 200°C.
D: One side with PSA type adhesive, generally of acrylic type, very thin, for gluing the heating element to the wall to be heated, the opposite side being equipped with a bonded or vulcanized silicone insulating foam, providing thermal insulation towards the outside.
E: Heating element glued to a heat conductive metal plate. This solution provides a good temperature homogeneity of the surface and allows to reach higher surface loads.
F: Heating element glued to a heat conductive metal plate. This solution provides a good temperature homogeneity of the surface and allows to reach higher surface loads. The outer face of the resistor receives a thermal insulating silicone foam, improving the heating efficiency.

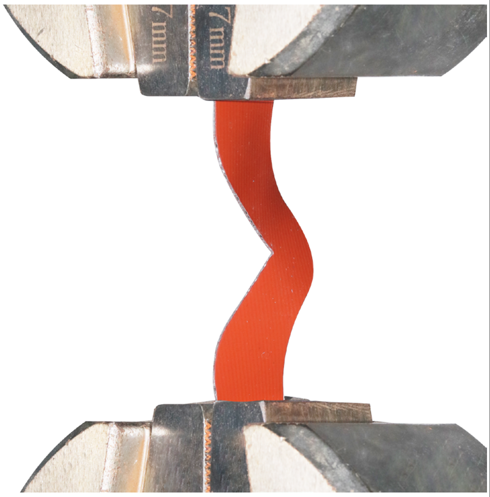


1: Flexible silicone heating element
2: Insulating foam (NBR-PVC for temperatures below 120°C, silicone foam for temperatures up to 220°C).
3: Pressure sensitive adhesive (PSA), usual thickness 50 microns in acrylic compositions.
4: Heat conducting metal plate. Usually aluminum.

5-5. Mechanical strength of flexible silicone heaters

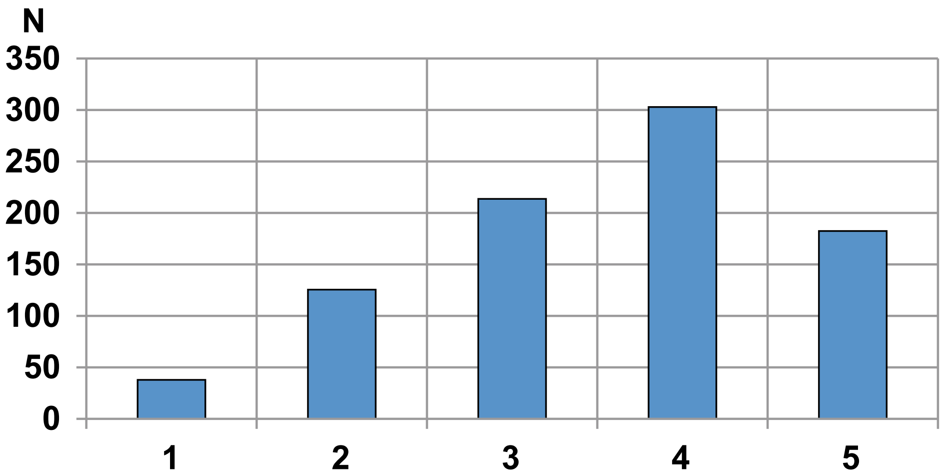
Silicone heaters are often subject to mechanical stress during installation or during use. To withstand these constraints technical solutions and validation tests are required.
The main constraints of their industrial applications are in particular:
1- The resistance to tearing, critical when heating elements are fixed by holes made in their thickness, for example to place screws, cords, rivets, or when asperities exist on the surface
2- The creep resistance, critical when the heating elements are permanently stretched by springs on a cylindrical tank, for example in heating belts.
3- Resistance to tearing of spring mounting hooks on heating belts
4- The pull-out resistance of electric power cables and wires, the minimum values of which are given by the electrical standards.
5- The resistance to separation of the various vulcanized layers, a critical parameter for the proper functioning of these heating elements.
6- Bending resistance, which makes it possible to verify that the heating elements can be placed on cylindrical walls, a critical parameter of heating belts and ribbons for electrical tracing.
7- The resistance to tearing of the silicone protective boxes of thermostats, limiters, temperature sensors, which must ensure that the safety or temperature control systems retain its function, therefore detaching them from the heating surface must not happen.
All these constraints have been the subject of validation tests before the devices are put into circulation on the market.

Tear strength
This tear strength test is made on the different thicknesses of the versions A(1.5/1.6mm), B (2.2/2.5mm), C (2.3/2.6mm) and D (3.2/3.5mm), on laser cut specimens with dimensions in accordance with EN 60335-2-17§21.110.1.
This test allows to check the quality of weaving used in the fiberglass reinforcement.



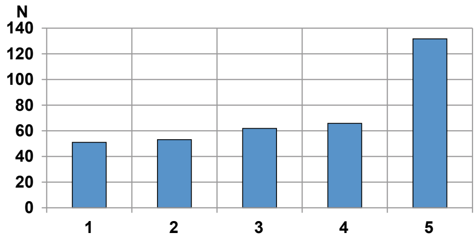
Sample used for testing

Tear strength testing equipment

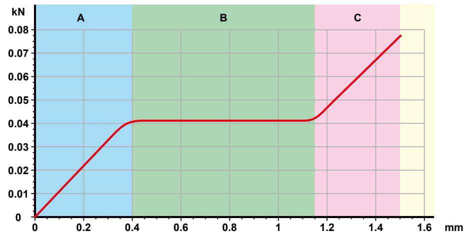


Comparative tear strength of the different thicknesses models
1 : 0.8mm ; 2 : 1.6mm ; 3 : 2.3mm ; 4 : 3.2mm ; 5 : 2.3mm with stainless steel mesh reinforcement

Creeping
In applications in which a permanent stress is applied, an elongation of the flexible silicone resistances may result in loosening and causing a gap with the heated surface. The resulting change in heat exchange can produce overheating. We therefore measured the force required to elongate 1.5mm in 30 minutes over a typical 300mm long heater in the different thickness configurations. (version with 1.6mm thickness is the reference basis).
This test allowed us to select the less creeping sensible fiberglass reinforced silicone sheets. The tests show that the creep is almost independent of the number of layers of glass fiber reinforced silicone, but above all depends on the quality of the bonding between the silicone resin and the fiberglass frame.



Comparative elongation strength at 0.05mm/min of the different thicknesses models 1 : 0.8mm, 2 : 1.6mm, 3 : 2.4mm ; 4 : 3.2mm 5 : 2.4mm with stainless steel mesh reinforcement



Creep curve type of a sheet of reinforced silicone fiberglass. In section A, the elongation is proportional to the applied force. In this section, the silicone is lengthened by opposing a resistance proportional to its elasticity. In section B, the elongation occurs without increasing the tensile force: this is due to the deformation of the fiberglass braiding meshes that separate from the silicone. In section C: the mesh of the weft can no longer be deformed, and the tension is applied directly on the fiberglass threads which will gradually break.

Type of sample tested (350 x 35mm)

Sample during testing

Holding hooks resistance to tearing

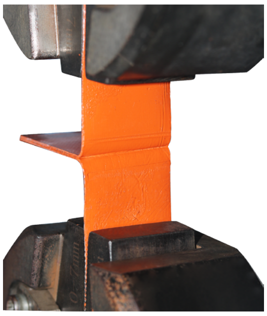
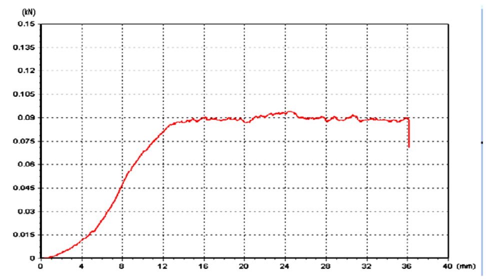
The tearing of a hook used to tension the heating belts will cause its falling from the barrel on which it is installed, and consequently the overheating and the immediate destruction of the belt, which may be the cause of a fire.

Thanks to the technology used, the force required to pull the hook supports off the heating belt is at least 50% greater than the force required to deform and straighten the metal hooks

	
Tear force testing sample	**Tear force testing equipment**

Split resistance of the vulcanized layers

One of the critical and invisible defects of flexible silicone heaters is incomplete vulcanization of the layers between which the heating wire is inserted. This incomplete vulcanization may be due to insufficient pressure, insufficient temperature, too short a compression time, a poorly dosed silicone resin or whose shelf life is exceeded. This defect will cause the uncoupling of the layers, the formation of bubbles, and the premature destruction of the heating wire. It is therefore important to be able to quantify this adhesion in order to optimize the vulcanization parameters. This test makes it possible in particular to measure the aging of semi-vulcanized silicone resins, since their storage time is limited. It also allows to check the constancy of the vulcanization over a long length.

	
Vulcanized sample before decoupling test	**Curve of the decoupling force on a displacement of some cm. It can be noted that when the vulcanization quality is good (as shown in this chart), the decoupling force is constant, with an average separating force of 9 DaN for 10cm bandwidth.**

Flexing resistance

In flexible heaters, flexural strength is a parameter used to check if heating wires are correctly formed and embedded inside the fiberglass reinforced silicone sheets. This test, made in a special equipment, makes it possible to verify that a fold in the heating element according to a precise radius will not result in a mechanical stress of the conductor which would provoke its breaking immediately or eventually after some folding.

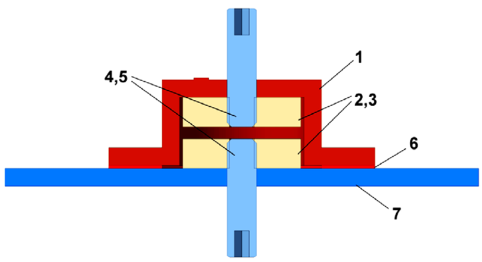
It is based on UL817 and EN60335-1-25 specifications.

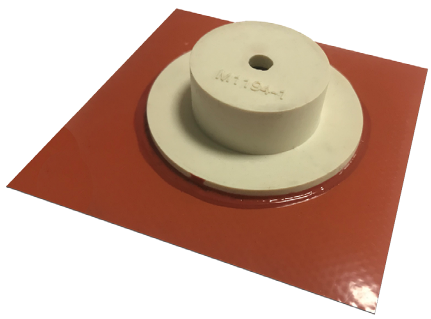
This test consists of an alternating flexion at 60 cycles per minute, bending at 90° (45° on each side of the vertical) on a 5mm radius. A load of 100 gr. per 100 mm width is added to the free end of the heating element. Criterion of acceptance: 500 cycles without heating wire breakage or change of more than 1% of its electrical resistance.

Flexible silicone heater during the flexion test

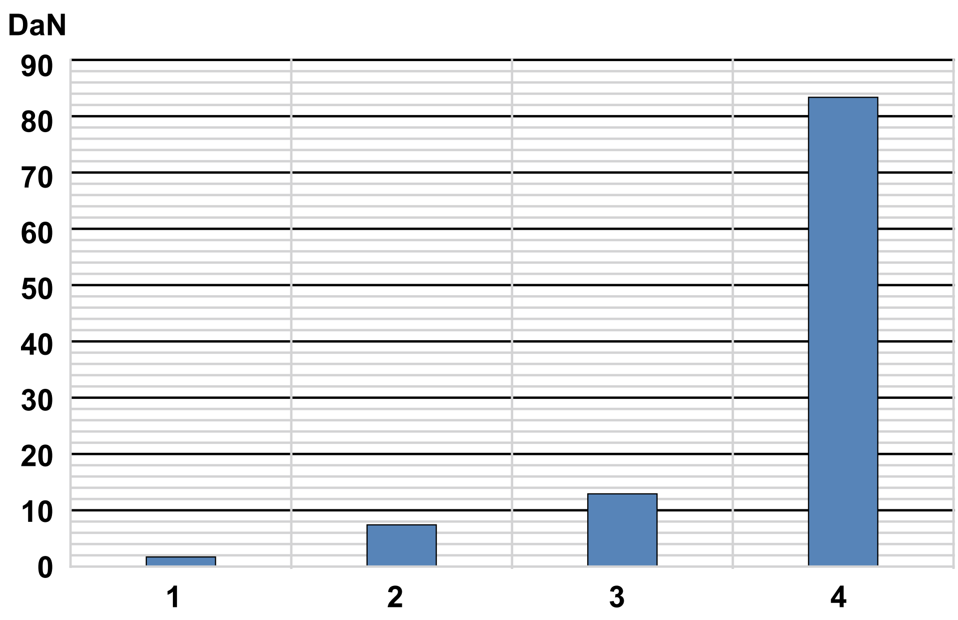
Tear strength of silicone protective housings of thermostats, limiters, temperature sensors.
All boots and protective boxes are vulcanized on the silicone sheets. These components are made of semi-flexible silicone with a hardness of 70 Shore A, having a flange with a large contact surface for vulcanization. As a result, their tear resistance is about 10 times greater than traditional glued models. In some models, after vulcanization, an additional filling, is made with heat-conductive RTV resin to provide protection against water penetration and / or better heat exchange with the surface of the heating element.

Comparison of the different vulcanization techniques and adhesives used for the bonding of silicone caps on flexible silicone heating surfaces.
These tests are carried out with a particular test boot allowing to have reproducible results.





Equipment used for comparative tests (Bonding surface: 10 cm²).
1: 70 Shore A silicone test cap;
2, 3: Inner washers;
4, 5: Traction screws;
6: Adhesive tested, vulcanized or polymerized;
7: Silicone heating element of 10 x 10 cm.



Comparative tear values

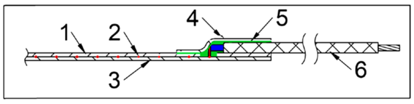
1/- Boot vulcanised at 180°C with two-component silicone adhesive: Average value 1.9DaN
2/- Boot glued with a high temperature single component silicone resin (RTV) polymerizing at room temperature: Average value 7.6DaN
3/- Boot glued with a high temperature single component high strength silicone resin (RTV) polymerizing at room temperature: Average value 13DaN.
4/- Boot vulcanised at medium temperature with silicone resin used in our production: Average value 84DaN. This represent 8.4DaN tear strength by cm² of bonded surface.

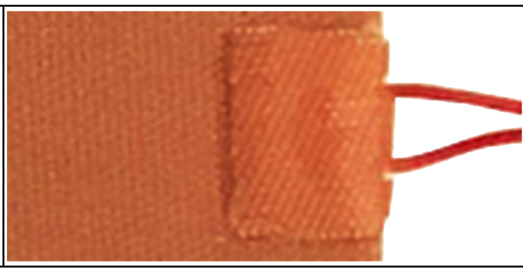
5-6. Connection methods for wires, cables, temperature sensors and thermostats

Two types of power lead connections are used in flexible silicone heaters:
- The connection by independent wires (one for each phase), intended for the heaters whose incorporation in an apparatus is carried out by the manufacturer of this apparatus. The gauge of conductors is determined by the power of the heating element. In this version, the mechanical resistance to tearing is achieved by a vulcanized patch.
- The connection by a cable, with two or three conductors, usually equipped with a plug, for devices intended for an end user. In this case the mechanical resistance to tearing is achieved by a vulcanized silicone boot, and possibly a locking system of the cable by mechanical clamping. Under the most critical operating conditions the vulcanized boot can be riveted to the heating element.
The tearing values to which cables and wires are subjected comply with the specifications of EN60335-1-25.12:
- 3 DaN for heating elements with a mass of less than 1 kg,
- 6 DaN for those with a mass of 1 to 4 kg,
- 10 DaN for those over 4 kg.
These constraints determine the design and characteristics of the patches and caps used

Connection of wires on flexible silicone heaters (IP54)

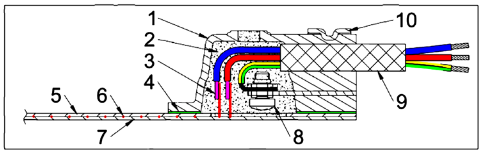
This connection, the most common on small dimensions flexible heaters, is made by a silicone patch vulcanized on the solder between the power supply conductors and the heating wires. It provides mechanical support and a relative ingress protection (IP54).

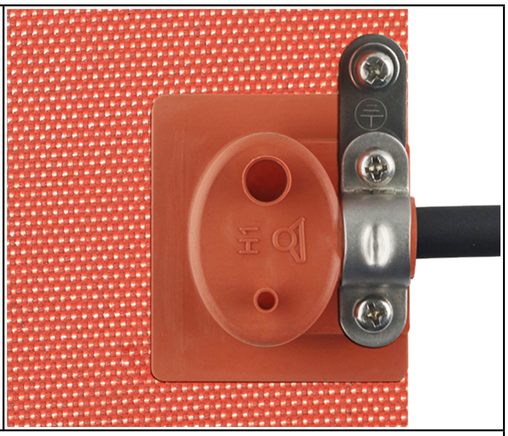




1: Fiberglass reinforced silicone sheet (Upper side).
2: Heating wire.
3: Fiberglass reinforced silicone sheet (Lower side).
4: Wire outlet fiberglass reinforced silicone patch
5: Vulcanized silicone resin (in green) fixing the patch on the silicone upper sheet and on the wires.
6: Power supply wires.

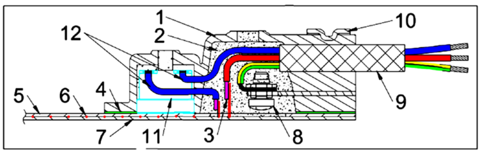
Connection of cables on flexible silicone heaters (IP65)
These caps allow the connection of 3 conductors round cables. They allow to connect the earth of the power cord to an internal terminal, useful to connect the flexible resistances with a metal grid. An external screw terminal is also grounded, for the connection of metal parts of tanks or heated walls. The filling of the boot with a silicone resin makes the assembly extremely resistant to tearing off and guarantees an IP65 degree of water and dust ingress.

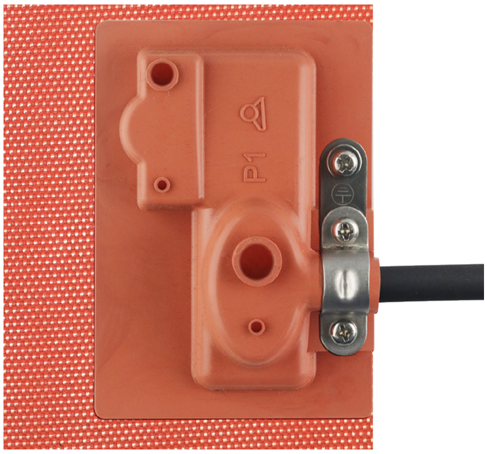




1: Protection boot
2: Silicone resin filling
3: Power supply wires
4: Vulcanized resin fixing the boot on the silicone heater
5: Fiberglass reinforced silicone sheet (Upper side)
6: Heating wire
7: Fiberglass reinforced silicone sheet (Lower side)
8: Ground terminal
9: 3-conductor power supply cable
10: Stainless steel clamp for power supply cable

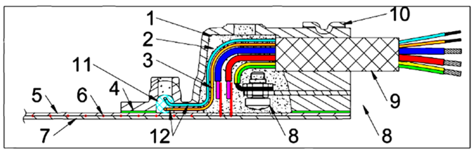
Connection of cables and temperature limiters on flexible silicone heaters (IP65)
These caps allow the connection of 3 conductors round cables. They allow first to connect the earth of the power cord to an internal terminal, useful to connect the flexible resistances with a metal grid. An external screw terminal is also grounded, for the connection of metal parts of tanks or heated walls.
Secondly, they allow to connect a fixe setting bimetal temperature limiter in serial with the heating element. The filling of the boot with a silicone resin makes the assembly extremely resistant to tearing off and guarantees an IP65 degree of water and dust ingress.

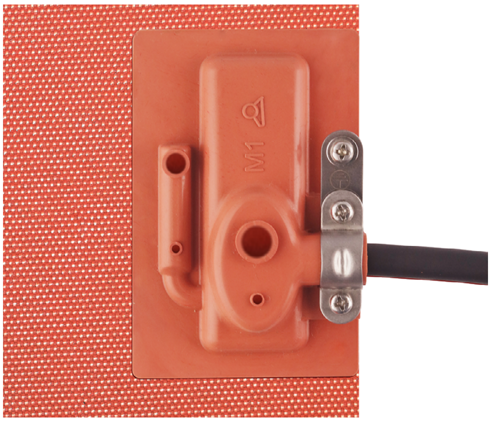




1: Protection boot
2: Silicone resin filling
3: Power supply wires
4: Vulcanized resin fixing the boot on the silicone heater
5: Fiberglass reinforced silicone sheet (Upper side)
6: Heating wire
7: Fiberglass reinforced silicone sheet (Lower side)
8: Ground terminal
9: 3-conductor power supply cable
10: Stainless steel clamp for power supply cable
11: Fixed setting bimetal thermostat
12: Bimetal thermostat connection wires

Connection of cable and temperature sensor on flexible silicone heaters (IP65)
These caps allow the connection of 5 conductors round cables. Firstly, they allow to connect the earth of the power cord to an internal terminal, useful to connect the flexible resistances with a metal grid. An external screw terminal is also grounded, for the connection of metal parts of tanks or heated walls.
Secondly, they allow to connect a 2 wires temperature sensor (2 wires Pt100, NTC or thermocouple). The filling of the boot with a silicone resin makes the assembly extremely resistant to tearing off and guarantees an IP65 degree of water and dust ingress.

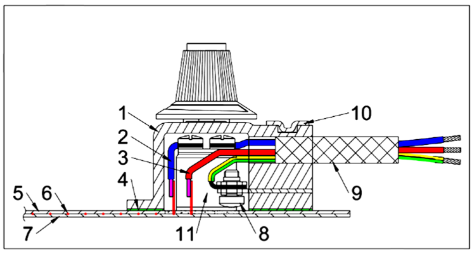


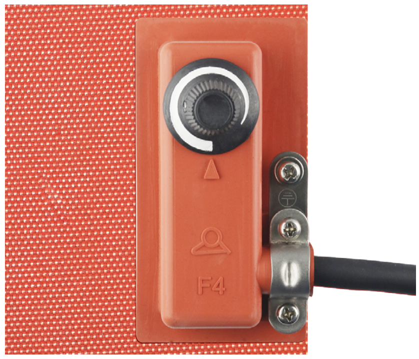


1: Protection boot
2: Silicone resin filling
3: Power supply wires
4: Vulcanized resin fixing the boot on the silicone heater
5: Fiberglass reinforced silicone sheet (Upper side)
6: Heating wire
7: Fiberglass reinforced silicone sheet (Lower side)
8: Ground terminal
9: 3-conductor power supply cable
10: Stainless steel clamp for power supply cable
11: Temperature sensor
12: Temperature sensor connection wires

Connection of cable and adjustable bimetal thermostat on flexible silicone heaters (IP54)

These flexible enclosures allow the connection of 3 conductors round cables. Firstly, they allow to connect the earth of the power cord to an internal terminal, useful to connect the flexible resistances with a metal grid. An external screw terminal is also grounded, for the connection of metal parts of tanks or heated walls.
Secondly, they allow to connect an adjustable bimetal thermostat measuring the temperature of the silicone heater surface on which it is in contact. The large bonding surfaces of the enclosure make the assembly extremely resistant to tearing off. This enclosure guarantees an IP54 degree of water and dust ingress protection.

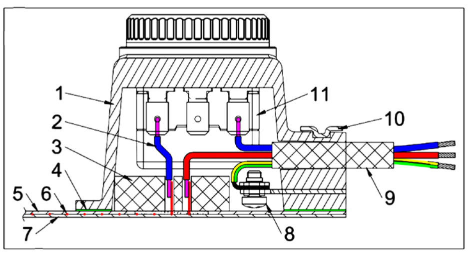


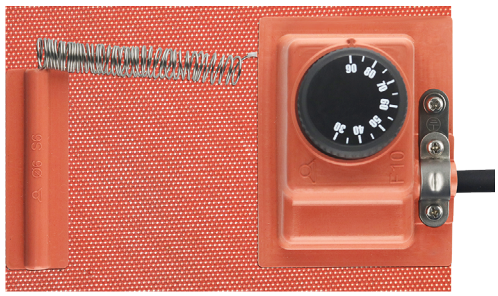


1: Flexible and reinforced protection enclosure
2: Wire connecting the thermostat to the heating element
3: Silicon foam sheet providing thermal insulation between thermostat body and heating element.
4: Vulcanized resin fixing the boot on the silicone heater
5: Fiberglass reinforced silicone sheet (Upper side)
6: Heating wire
7: Fiberglass reinforced silicone sheet (Lower side)
8: Ground terminal
9: 3-conductor power supply cable
10: Stainless steel clamp for power supply cable
11: Thermostat body

Connection of cable and adjustable bulb and capillary thermostat on flexible silicone heaters (IP54)

These flexible enclosures allow the connection of 3 conductors round cables. Firstly, they allow to connect the earth of the power cord to an internal terminal, useful to connect the flexible resistances with a metal grid. An external screw terminal is also grounded, for the connection of metal parts of tanks or heated walls.
Secondly, they allow to connect an adjustable bulb and capillary thermostat. The silicone foam sheet protect the thermostat body from the heating surface temperature. The large bonding surfaces of the enclosure make the assembly extremely resistant to tearing off. This enclosure guarantees an IP54 degree of water and dust ingress protection.





1 : Flexible and reinforced protection enclosure
2 : Wire connecting the thermostat to the heating element
3: Silicon foam sheet providing thermal insulation between thermostat body and heating element.
4 : Vulcanized resin fixing the boot on the silicone heater
5 : Fiberglass reinforced silicone sheet (Upper side)
6 : Heating wire
7 : Fiberglass reinforced silicone sheet (Lower side)
8 : Ground terminal
9 : 3-conductor power supply cable
10 : Stainless steel clamp for power supply cable
11 : Thermostat body

5-7. Parameters of electrical insulation of flexible silicone heaters

Insulation resistance at ambient temperature

The insulation resistance decreases with the length of heating wire used. If this length can go down to a few meters in the small silicone heaters, it can exceed more than 250 meters on the large models. In production, the insulation values are 100% measured at ambient temperature. Our minimum acceptance limit is 0.1Gohms (100x the limit of EN60335-2-17§ 19.112.3).

This measurement is carried out with the heater sandwiched between two metal sheets covering the entire surface and pressed against each other with a load of 35 DaN/m².

Device for measuring the insulation resistance.
The measured values are always greater than 0.1Gohm

Electric strength at ambient temperature

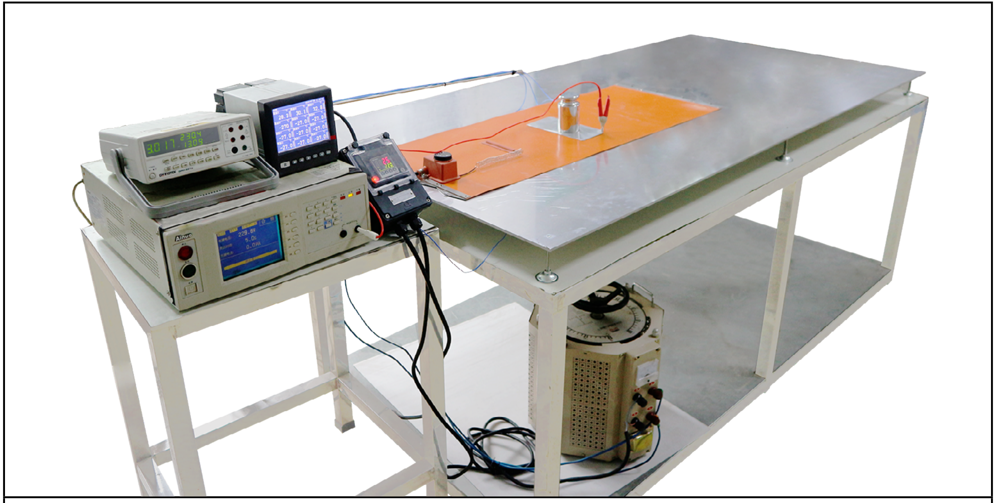
In all protected heating elements, there is a leakage current passing through their insulation. This leakage current increases with the applied voltage.

In the case of silicone heaters, a production test for measuring the total leakage current is performed by placing the heater between two metal plates and applying a voltage of 1750 volts between the conductors and the metal plates according to 60-335-2 -17 § 22.115. In application of the EN60519-1 standard, the maximum leakage current allowed during 1 minute is a function of the nominal ampacity of the heater, it is 3mA for ampacities less than 7A (1600W in 230V) and 0.5mA per ampere for higher currents (eg 10mA for 2000W, 15mA for 3000W). The large value of the leakage current on the large dimensions heaters requires their connection to a power supply circuit protected by a differential circuit breaker calibrated at 20mA.

Measuring equipment for total current leakage at cold condition

Leakage current at working temperature

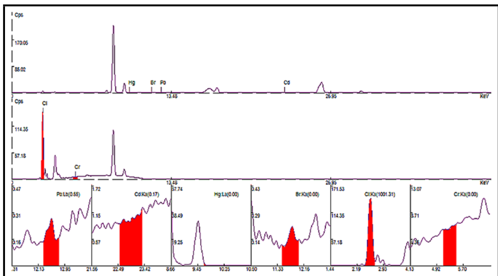
Leakage current measurement on hot and accessible surfaces is a parameter intended to verify the safety of an appliance to avoid electric shock when touched while it is in operation. This is a way to check that its electrical insulation does not degrade and remains sufficient when the operating temperature is reached. The tests consist, in accordance with the articles of standards EN60335-1-13.1 and 13.2, to place a metal plate of 10 x 20 cm (simulating the size of a hand) on the heater, and to measure the current passing between this plate and the live conductors when the silicone heater has reached its maximum temperature, which can rise up to 200°C on some models. The maximum limit value is 0.75mA at 240V. Our tests are validated by an average value of 6 measurements made at different locations, under a power equal to 1.15 times the nominal power.



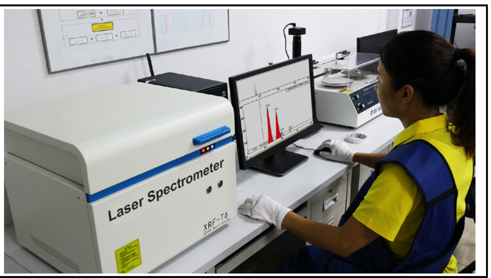
Measuring equipment for total current leakage at hot condition

5-8. Rohs and Reach compliance

Rohs: The materials used in the flexible silicone heaters comply with the European directive 2015/863 Annex II amending Directive 2011/65.
These tests are part of the standard quality control at Ultimheat, and are performed systematically for the validation of each supplier's delivery.
They are made in our own laboratory, with latest-generation measuring instruments.
If desired, we can provide certificates made by an approved external laboratory.
Reach: The materials used in the flexible silicone heaters comply with the REACH European Directives according to the June 2017 directive adding 173 substances SVHC (Substances of Very High Concern) from the list published by ECHA on 12 January 2017, applying to the Reach directive 1907/2006.
Certificates made by an accredited external laboratory available on request.



Rohs spectrogram of a fiberglass reinforced silicone sheet (Ultimheat laboratory)



Spectrometric analysis in progress (Ultimheat Laboratory)