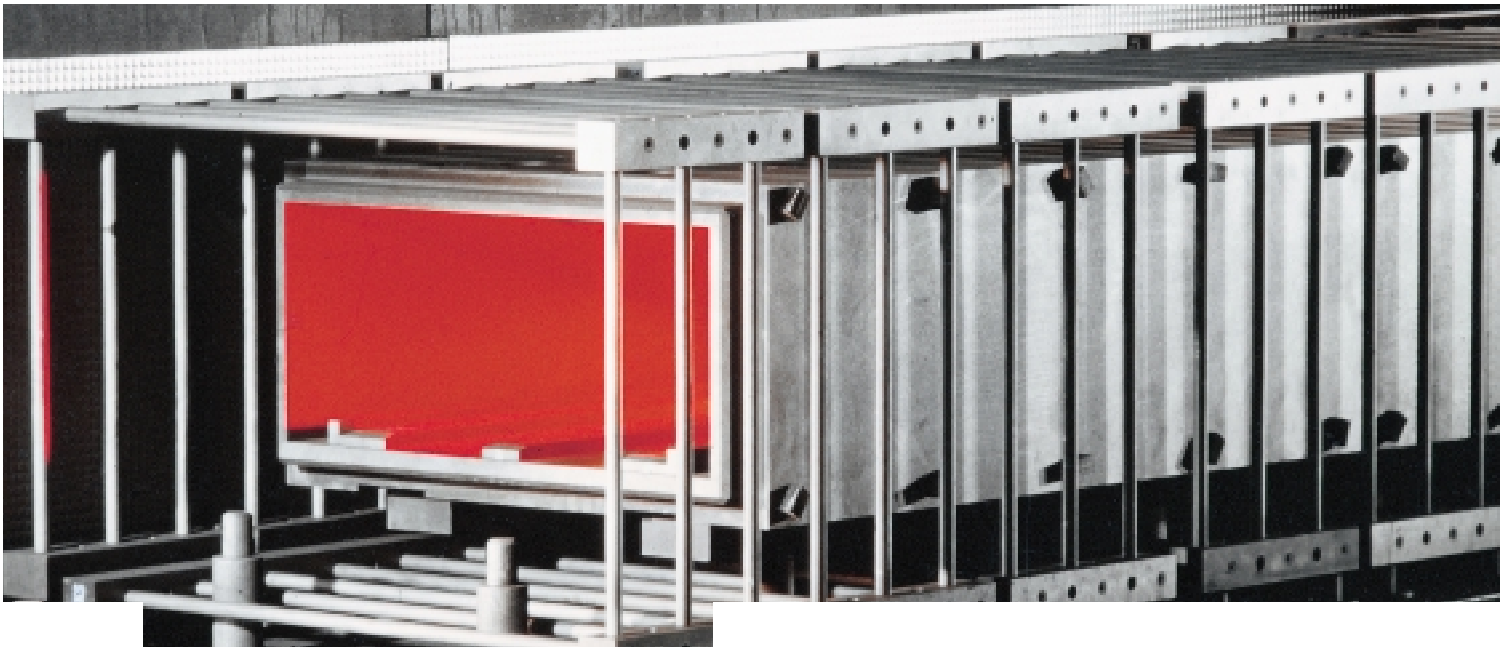
Heating Systems in Specialty Graphite

for Electric Heating of High-Temperature Furnaces



SGL CARBON GROUP

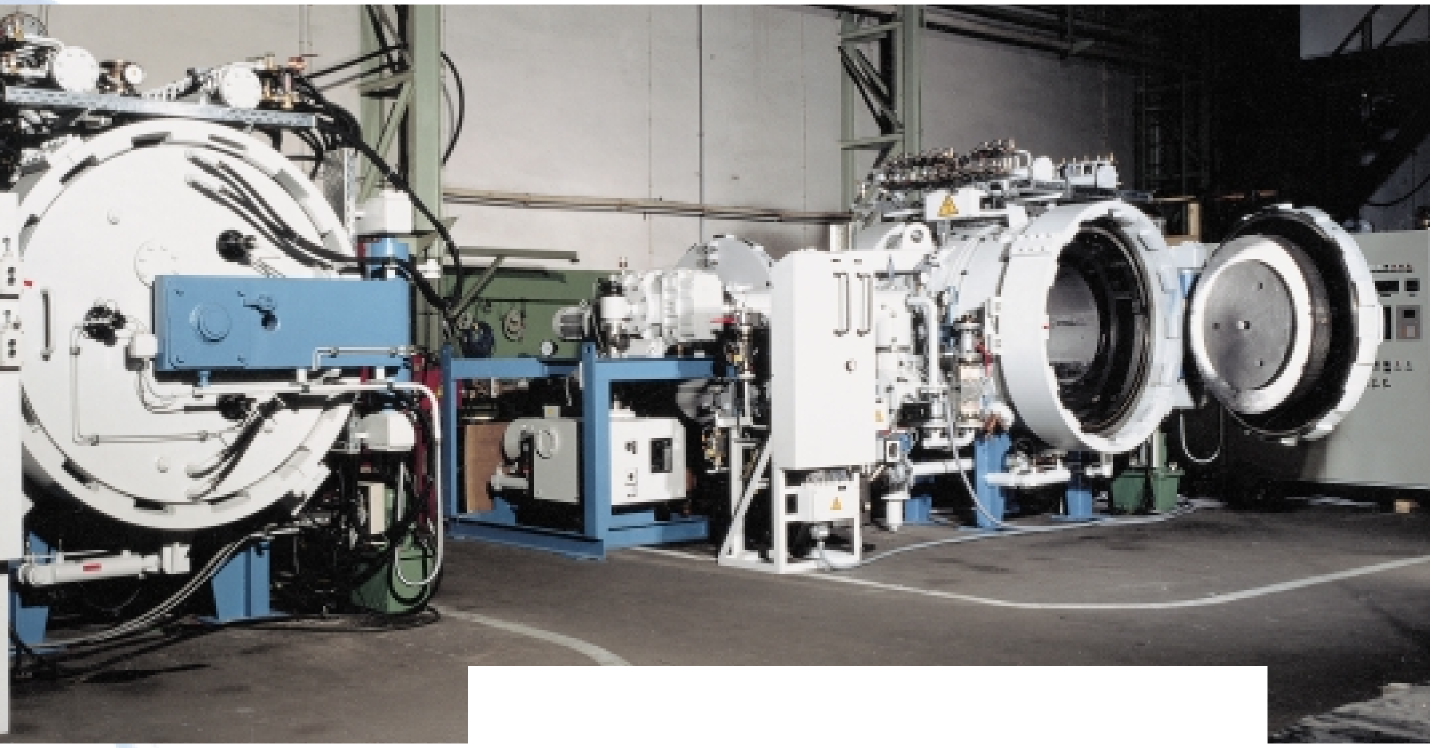
Specialty Graphites from SGL CARBON: Custom-Made Products for Key Industries

- High thermal stability
- Good electrical conductivity
- High thermal conductivity
- High resistance to thermal shock
- High resistance to corrosion
- High purity
- Low wettability
- High mechanical strength
- Good sliding properties

Specialty graphites from SGL CARBON are matched to the needs of different applications by specific combinations of properties:

e.g. for "Industrial applications"

Electric Heating Elements and Heating Systems



Electric heating of high-temperature furnaces allows thermal processing in many sectors of industry.

Systems used for heating the useable space of industrial furnaces are subject to varying demands which depend on the thermal process concerned.

These demands include not only high thermal stability, high electrical loading capacity and good mechanical strength; in addition, the material used for the heating systems must be chemically pure and resistant to both aggressive media and thermal shock.

The useable space should be optimized to ensure economical operation. This is done by employing space-saving heating systems matched to the furnace concerned. Other crucial factors in economical operation are low mass, ease of assembly and long service life.

A special material meeting all of these criteria is needed to ensure optimum performance.

Materials for Electrical Resistance Heating Elements

Whereas the use of metal and ceramic heating elements is usually limited to temperatures up to about 2000 °C, specialty graphite material can be used for the entire range of temperatures up to 3000 °C.
Specialty graphites offer a unique combination of properties with which they can meet the vast majority of requirements for optimum performance as electrical resistance heating elements and heating systems.
SGL CARBON supplies specialty graphite grades MNC and MNT, which have been specially developed for use as electrical resistance heating elements.
Both grades consist of fine-grain graphite with a dense and highly homogeneous structure. They are extruded in tubular form in relatively small wall thicknesses.

Both specialty graphite grades offer clear advantages.

High thermal stability

Grades MNC and MNT can be used in vacuum up to 2200 °C. The attainable element temperatures depend on the extent of the vacuum. Because of the excessive carbon vapor pressure at temperatures above 2200 °C, however, the material should not be used in a vacuum at temperatures above 2200 °C. Operation is possible in non-oxidizing, reducing or inert protective atmospheres at temperatures up to 3000 °C.

High electrical loading capacity

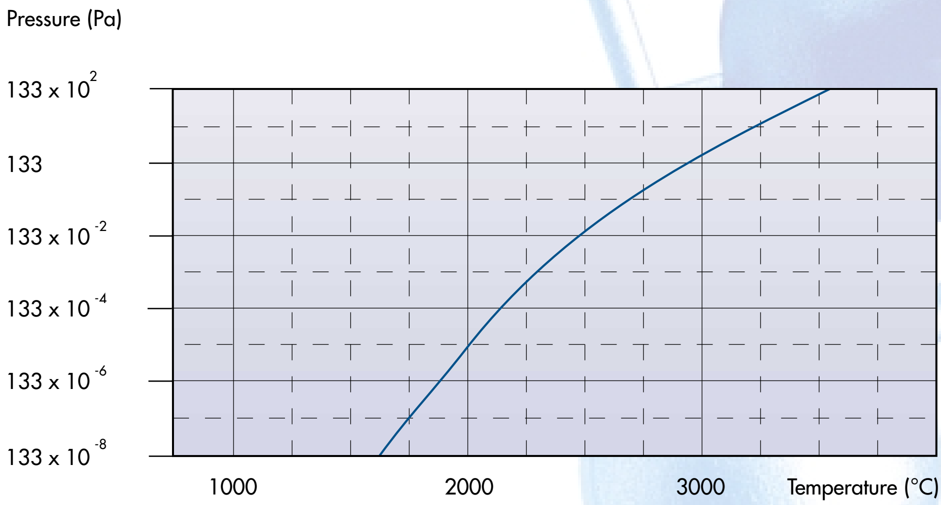
The maximum loading permitted is dependent on temperature. We recommend a loading not exceeding 35 W/cm² in the hot-zone surface area for continuous operation at temperatures up to around 1000 °C. For short-term operation, the heating elements can be run at 50 W/cm² or more. The maximum loadings should be less at temperatures above 1000 °C.

Optimum resistivity

Despite its very high bulk density, MNC/MNT grade material also has extremely high resistivity. In combination with the thin-walled tube cross-section, this makes for high electrical resistance of the heating elements. They can therefore be operated at relatively low amperage values even at high temperatures. This fact can be used to great advantage in calculating the design of current supply systems.

High resistance to thermal shock

Owing to their thin-walled tubular form and associated low mass, MNC/MNT grade heating elements allow very short heating and cooling times and sudden changes in temperature. Moreover, core overheating cannot occur during high-temperature operation.



Carbon vapor pressure during high-temperature operation

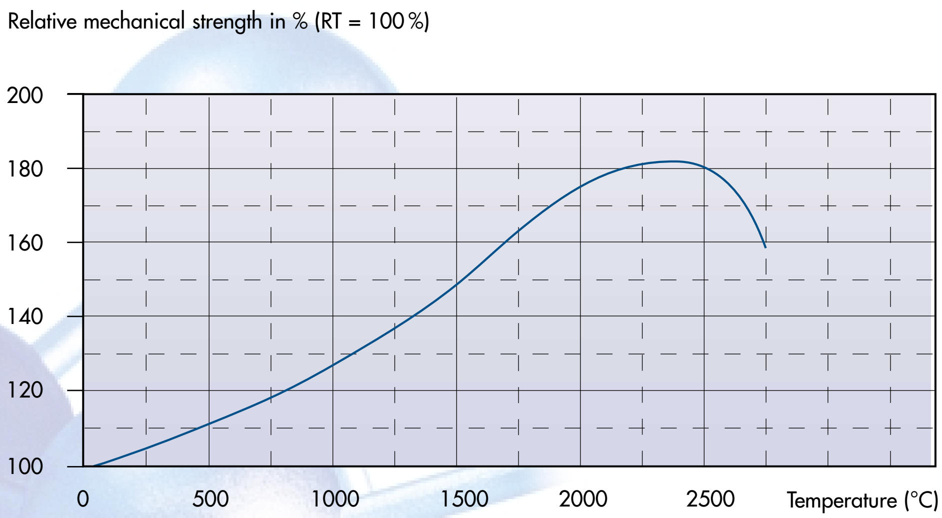
and Heating Systems

Homogeneous glowing pattern

The constant wall thickness of tubular heating elements makes for a uniform glowing pattern, which is a major advantage in achieving optimum temperature distribution.

High mechanical strength

The very high mechanical strength increases even further as temperatures rise to 2600 °C. This allows structural designs with large self-supporting lengths. At temperatures above 2600 °C, however, the mechanical strength gradually declines.



Relative mechanical strength profile as a function of temperature

Chemical resistance

Heating elements made of specialty graphite grades MNC and MNT are resistant to aggressive media such as fluorine, chlorine and their hydrogen compounds. They are likewise resistant to molten glass and metals such as copper, tin, zinc, cadmium, germanium, lead, aluminum, silver, gold, mercury and their alloys.

Alkalis and earth alkalis, as well as transition metals and their oxides cause temperature-dependent corrosion. Basic oxides, hydrides, hydroxides, borides, silicides and phosphides attack graphite at high temperatures to form carbides. Under such conditions, graphite heating elements should be protected by suitable design measures such as the incorporation of furnace chambers.
Like any other graphite material, specialty graphite grades MNC and MNT are attacked by oxidizing agents such as oxygen, air, CO_2, NO_2, steam and their mixtures. The attack begins slowly from around 400 °C, then more rapidly from around 600 °C.

High purity

The relatively high purity of the material ensures that the charging material is not contaminated.

Long service life

Even at high temperatures, heating elements in specialty graphite grades MNC and MNT undergo no embrittlement due to recrystallisation, nor do coarse grains form as a result of ageing. This behavior distinguishes them from metal and ceramic heating conductors. Service life is limited only by wear due to the undesired effect of oxidation. Oxidizing constituents in the furnace atmosphere may come from the charging material or result from contaminated protective gas or insufficient vacuum. Heating elements in specialty graphite grades MNC and MNT are usually supplied unmachined over the entire hot-zone length. This means the high-density skin produced during extrusion is retained and offers excellent additional protection. As a result, oxidative wear is at least delayed.

Service life is also shortened by carbon vapor pressure, which rises at very high temperatures. Even so, MNC and MNT graphite heating elements are commonly employed at temperatures up to 3000 °C.

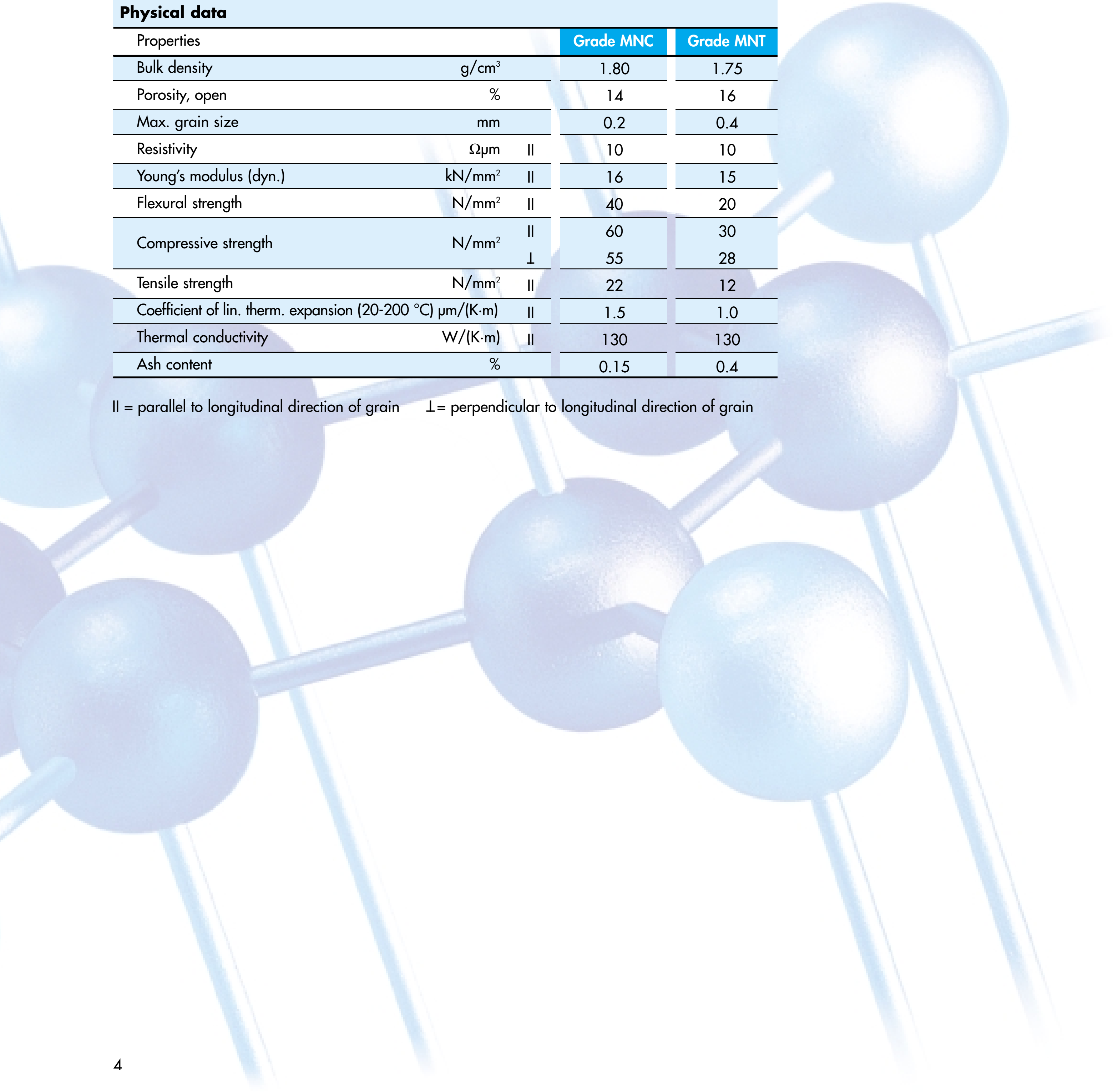
Material Properties

Specialty graphite grades MNC and MNT for electrical resistance heating elements.

Physical data

Properties			Grade MNC	Grade MNT
Bulk density	g/cm³		1.80	1.75
Porosity, open	%		14	16
Max. grain size	mm		0.2	0.4
Resistivity	Ωμm	II	10	10
Young's modulus (dyn.)	kN/mm²	II	16	15
Flexural strength	N/mm²	II	40	20
Compressive strength	N/mm²	II	60	30
		⊥	55	28
Tensile strength	N/mm²	II	22	12
Coefficient of lin. therm. expansion (20-200 °C)	μm/(K·m)	II	1.5	1.0
Thermal conductivity	W/(K·m)	II	130	130
Ash content	%		0.15	0.4

II = parallel to longitudinal direction of grain ⊥= perpendicular to longitudinal direction of grain



Electrical contacts in specialty graphite grades with high electrical conductivity.

Specialty graphite grades MNC and MNT are used for heating elements because of their relatively high electrical resistance. In contrast, the specialty graphite grades used for electrical contacts should have high electrical conductivity and low thermal expansion to ensure a low-loss current supply.
We therefore recommend that our specialty graphite grades FLM, MLM and HLM be used for electrical contacts, contact bridges and connecting elements.

Specialty graphite grades FLM, MLM and HLM for electrical contacts.

Physical data

Properties	Unit		Grade FLM		Grade MLM		Grade HLM	
			ø 30-60 mm	ø >60-80 mm	ø 75-275 mm	□≤610x610 mm	ø 75-350 mm	□≤670 mm
Bulk density	g/cm³		1.73	1.73	1.69	1.73	1.74	1.70
Porosity, open	%		17	19	22	18	16	17
Max. grain size	mm		0.4	0.8	1.7	3.3	0.8	0.8
Resistivity	Ωμm	II	6	6	6.4	6.8	6.7	7.3
		⊥	12	12	10.4	8.3	9.2	9.4
Young's modulus (dyn.)	kN/mm²	II	16	15	10	12	14	10
		⊥	6	6	8	9	10	9
Flexural strength	N/mm²	II	24	21	18	22	26	18
		⊥	15	14	14	17	19	17
Compressive strength	N/mm²	II	38	32	38	46	55	39
		⊥	36	28	29	36	40	35
Tensile strength	N/mm²	II	13	11	13	15	18	13
		⊥	7	6	10	12	13	12
Coefficient of linear thermal expansion (20-200 °C)	μm/(K·m)	II	0.7	0.7	1.0	2.6	2.1	2.1
		⊥	3.2	3.2	2.2	3.4	3.7	3.1
Thermal conductivity	W/(K·m)	II	200	200	210	200	200	180
		⊥	110	100	130	160	150	140
Ash content	%		0.15	0.15	<0.2	<0.1	<0.1	<0.1

II = parallel to longitudinal direction of grain ⊥ = perpendicular to longitudinal direction of grain

Dimensions

Heating tubes in specialty graphite grades MNC and MNT are regularly available in standard dimensions.

The range of available MNC and MNT dimensions covers their entire scope of use in high-temperature furnaces up to maximum heating capacities.

The standard lengths available up to a maximum of 3000 mm can be used in the design and construction of electric heating systems for large industrial furnace plants.

Standard dimensions

Length [mm]	Grade MNC				Grade MNT			
	Nominal diameters Do/Di [mm]							
	8/2	15/5	20/10	32/22	32/22	37/25	50/37	70/50
500	○		○					
800		○		○				
900				○				
1000	○		○	○	○	○	○	○
1300				○				
1400		○						
1500				○	○	○	○	○
1600		○		○				
2000			○	○	○	○	○	○
2500					○	○	○	○
3000				○	○	○	○	○

Nominal dimensions. Lengths deviating from standard dimensions can be supplied on request.

Dimensional tolerances.

The dimensions stated are nominal values. Heating tubes are usually employed with unmachined surfaces. This means the high-density skin produced during extrusion is retained and offers additional protection against any corrosive attack.
Since retaining the extrusion skin influences total resistivity, oversize tolerances must be allowed for in the design calculations for the heating elements' current supply system.

Typical diameter tolerances

Unmachined tolerances	Grade MNC				Grade MNT			
	Nominal diameters Do/Di [mm]							
	8/2	15/5	20/10	32/22	32/22	37/25	50/37	70/50
Outside diameter Do (mm)	+ 1	+ 1	+ 1	+ 2	+ 2	+ 2	+ 2	+ 2
Wall thickness (mm)	±0.3	±0.4	±0.4	±0.5	±1.0	±1.0	±1.0	±1.5

Maximum deviation from straight line is about 0.5 % of length.

Uses

Electric heating elements in specialty graphite grades MNC and MNT are suitable for a wide field of uses.

These heating elements can be used in vacuum up to 2200 °C and in a reducing or inert protective atmosphere up to temperatures of 3000 °C. Suitable protective gases are all rare gases, nitrogen, carbon monoxide, dry hydrogen and any mixture of these gases.

Maximum heating element temperatures as a function of furnace atmosphere

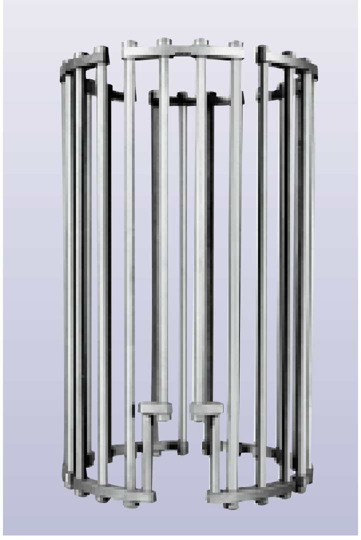
Atmosphere	Maximum element temperature in °C
Vacuum	2 200
Nitrogen	2 500
Hydrogen, dry	2 500
Endothermic atmosphere, dry, Co_2-free	2 500
Rare gases	3 000
Carbon monoxide	3 000

These conditions allow optimum heating of industrial furnaces up to maximum temperatures for nearly all thermal processes.

Purpose-made heating systems ensure optimum performance and excellent temperature accuracy in high-temperature furnaces.

Heating tubes in specialty graphite grades MNC and MNT can be combined in a variety of ways. As a result, complete heating systems with optimum performance and high temperature accuracy can be designed to match the furnace concerned.
The structural design can be adjusted to achieve high cost-efficiency by making optimum use of furnace space.

Contacts and connecting elements in specialty graphite grades FLM, MLM and HLM can be used to design heating systems of any configuration without problems.



Selecting the Materials

Selecting the correct MNC and MNT graphite heating tubes helps ensure heating systems with optimum performance and a uniform temperature profile in the furnace.

The design of the heating systems must be based on the heating capacity required for thermal treatment, and also on the heat loss and the respective maximum operating temperature in the useable space of the furnace.

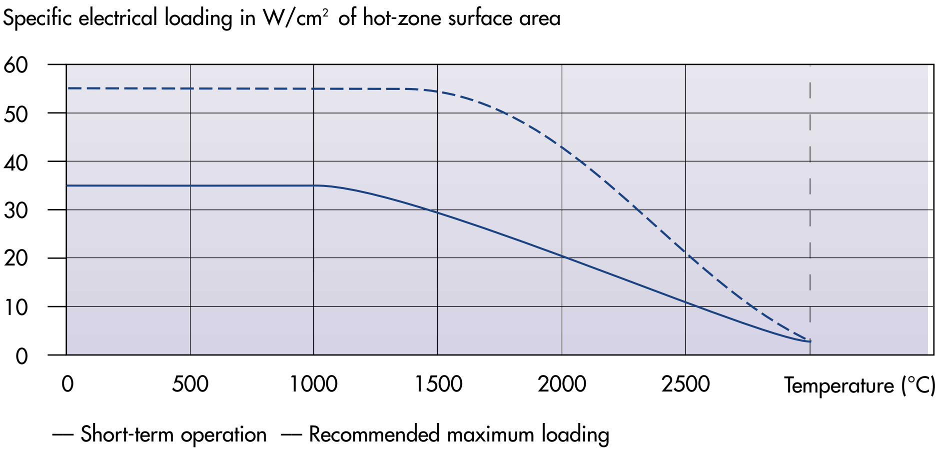
The recommended limits for the specific electrical loadings must be allowed for when graphite heating tubes are selected.

Limits for specific electrical loadings in short-term operation.

Spec. electr. loading in W/cm² of hot-zone surface area at furnace temperatures

Furnace temperatures °C	Grade MNC				Grade MNT			
	Hot zone, outside diameter [mm]							
	8	15	20	32	32	37	50	70
<1500	35	55	55	55	55	55	55	55
1500 - 2200	25	35	35	35	35	35	35	35
>2200	<15	<20	<20	<20	<20	<20	<20	<20

A maximum current density of 5 A/mm² relative to the cross-section of the graphite heating tube should not be exceeded.

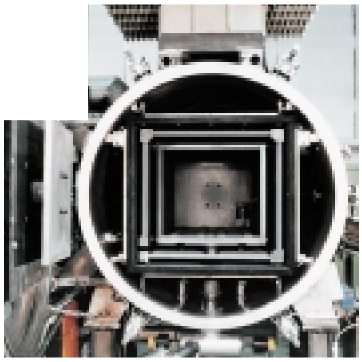


Recommended limits for the specific electrical loading in W/cm² of hot-zone surface area as a function of temperature.

For cost-efficient continuous operation, the specific surface loadings should of course be lower.

Design

Heating systems with MNC and MNT graphite heating tubes can be designed to match the furnace concerned.



Allowance should be made for the minimum distances from the furnace insulation and furnace chambers, if any. A clearance of roughly three times the heating tube diameter should be maintained.

The clearance between adjacent heating tubes should be about five times the heating tube diameter.

If the heating tubes are installed in relatively large self-supporting lengths, these distances should be increased by roughly 10 % to avoid problems due to electrodynamic power effects.

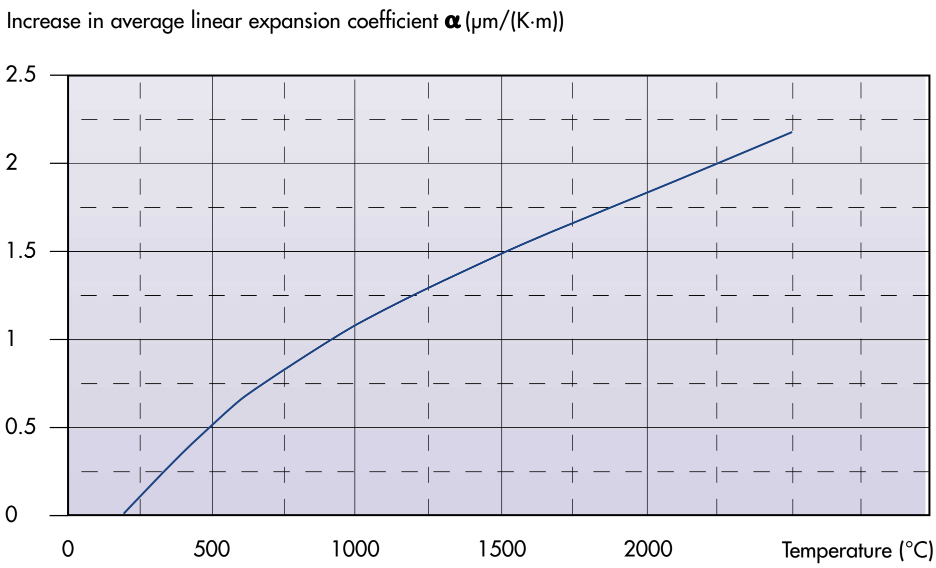
Thermal expansion must also be specially allowed for in measures to secure the heating system in the furnace.

Increase (absolute) in the average linear expansion coefficient α from 200 °C for MNC and MNT graphite heating tubes.

The heating tubes can be connected either in series or in parallel. It is recommended, however, that not more than 4 to 6 heating tubes be connected in series within one group.

A mixed series/parallel connection is recommended in order to keep the total amperage of the heating system as low as possible.

For operation with a three-phase current, the groups can be connected in a star or delta arrangement.



The increase should be added to the typical value of the linear expansion coefficient at 20-200 °C.

Layout of electrical connections and contacts is governed by the design of the heating system.

As a general design principle, care should be taken to ensure that the electrical connections between specialty graphite heating tubes are located inside the furnace.

If possible, only the graphite contacts for the current supply should be passed through the furnace wall. Here, measures must be taken to ensure both gas-tightness and electrical insulation. The graphite contacts are best connected to enveloping water-cooled copper contacts used for the current supply.

Owing to their thermal expansion, the passages for the graphite contacts cannot be designed to be absolutely gas-tight. For this reason, the connection on the outer furnace wall is usually sealed with a protective hood.

The current supply into the connection hood can be installed without problems using commercially available gas-tight leads.

The heating current supply for the plant is designed to match the heating system.

The heating system should be operated using step transformers or – for fine power control – thyristor controllers with fixed-ratio transformers connected on the load side.

To avoid overloading the heating system, the thyristor controllers should have a power-limiting facility; limiting the current alone is not enough.

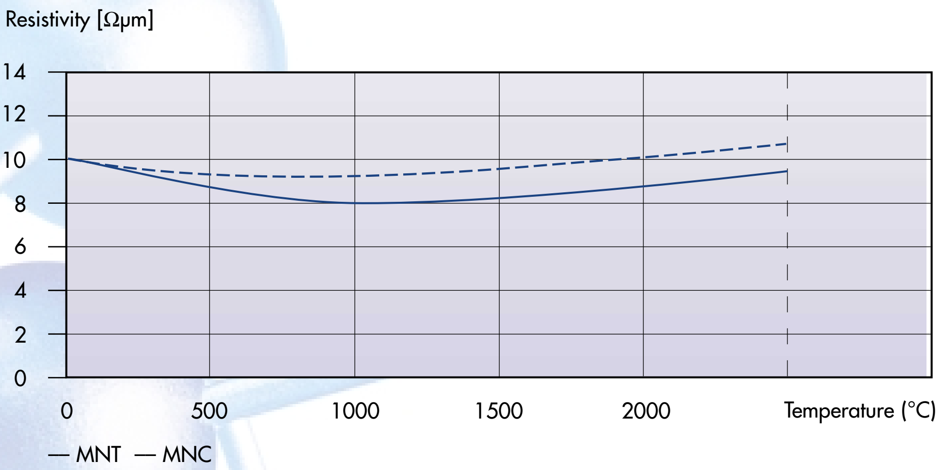
The design of the current supply system is based on the electrical operating data for voltage and amperage calculated for the heating system. However, it must be borne in mind that the graphite heating tubes represent a temperature-dependent resistance minimum in the heating phase. This is best compensated for by allowing for a current reserve of about 25%.

Resistivity/temperature characteristics of MNC and MNT graphite heating tubes.

Despite their excellent physical properties, the heating tubes cannot be prevented from burning off slowly as a result of oxidation at high temperatures. Oxidative wear is due to small proportions of residual oxygen present after evacuation, to impurities in the protective gas, or to oxygen-containing products released by the charging materials.

Owing to a reduction in the tube cross-section, oxidation on the heating tubes leads to an increase in resistivity. This can be compensated for as required by a voltage reserve to ensure a constant heating capacity. The economically best voltage reserve is 30 to 40%, as this likewise covers the resistivity tolerance of the heating tubes.

Resistivity of specialty graphite grades MNC and MNT as a function of temperature



Appropriate design of the heating system allows ease of assembly and dismantling.

The heating systems are best designed so as to allow assembly in the furnace in a minimum of time. Such a design also facilitates dismantling if replacements need be made, thus keeping plant downtimes to a minimum. Defective heating tubes can also be replaced individually unless the heating system as a whole has undergone excessive ageing and total resistivity is already too high. We shall be glad to advise you on the joining technique required.

Special Designs

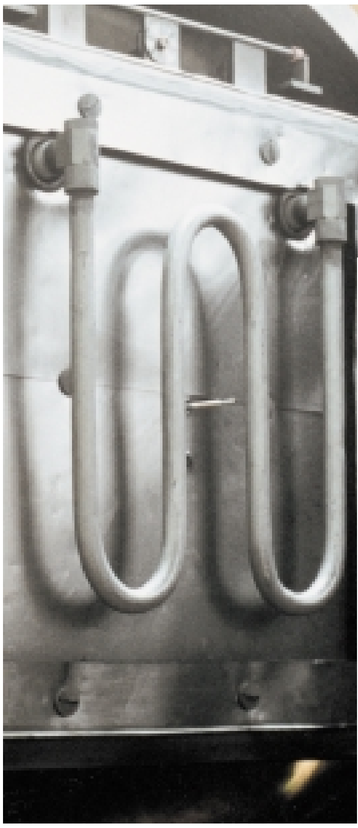
Special designs of MNC graphite heating tubes in U-, W- or spiral shape.

U- or W-shaped heating elements can be manufactured from straight MNC and MNT grade heating tubes by using an appropriate joining technique.

However, the production technology for heating tube grade MNC also allows the manufacture of ready-made U-, W- and spiral-shaped heating elements in special designs.

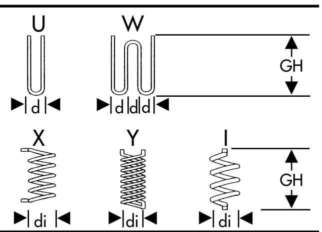
Special designs are specifically manufactured to customers' requirements.

Non-standard designs need special production facilities matched to the requirement concerned. Each design should therefore be manufactured only in reasonably large numbers in order to ensure cost-efficient production. Since special designs need to be produced from scratch, it must be borne in mind that the entire production time is 6 to 8 months. For this reason, replacement requirements should be included in the calculation of production numbers.



Special designs can be manufactured within specified dimensional limits.

Dimensional limits [mm]		Diameter Da/Di [mm] 15/5	20/10	32/22	Type
GH	max.	1000	1600	1800	U, W
d	min.	60	80	160	
	max.	200	250	320	
GH	max.	500	800	1000	X, Y, I
di	min.	100	150	200	
	max.	250	500	750	



GH = hot-zone height d = distance between axes di = spiral inside diameter

Our Service

Our technical service includes designing and planning heating systems matched to the furnace concerned.

In particular, our service includes proposals for the design of heating elements to suit the intended use, planning of heating systems to match the furnace concerned, and also calculation of the necessary electrical operating data.

We are also glad to provide advice on the design of electrical connection elements and contacts for the current supply system.

By allowing for technical plant conditions and process requirements, we design the entire range of graphite equipment for high-temperature furnaces, from structural elements to optimized charging systems.

This is done in close cooperation with our customers. On the basis of the necessary parameters for the high-temperature process concerned, we produce project drawings and submit them to our customers for agreement of technical details. The subsequent detailed drawings are the basis for implementing the furnace project. In our design work, we draw on our technical know-how and many years' experience in handling the materials concerned. The resulting high-temperature furnace ensures optimum performance and high cost-efficiency.

Commitment to Excellence

TQM

We believe that TQM is vital to SGL CARBON's success by providing a productive environment in which to achieve our strategic objectives. As we attain our objectives, we will continue to increase value for our customers, shareholders, and employees.

TQM requires striving towards excellence. Therefore, continuous improvement of all our processes, products and services is necessary.

We are committed to providing resources and support for necessary skill development to encourage a culture of continuous improvement. In return, it is the responsibility of every employee to play an active role in our TQM process.

TQM is a major component of our company philosophy, and therefore, it is to be applied in all day to day and strategic activities.

Robert J. Koehler
Wayne T. Burgess
Dr. Bruno Toniolo
Dr. Klaus Warning

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10 99/07E/E Printed in Germany

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