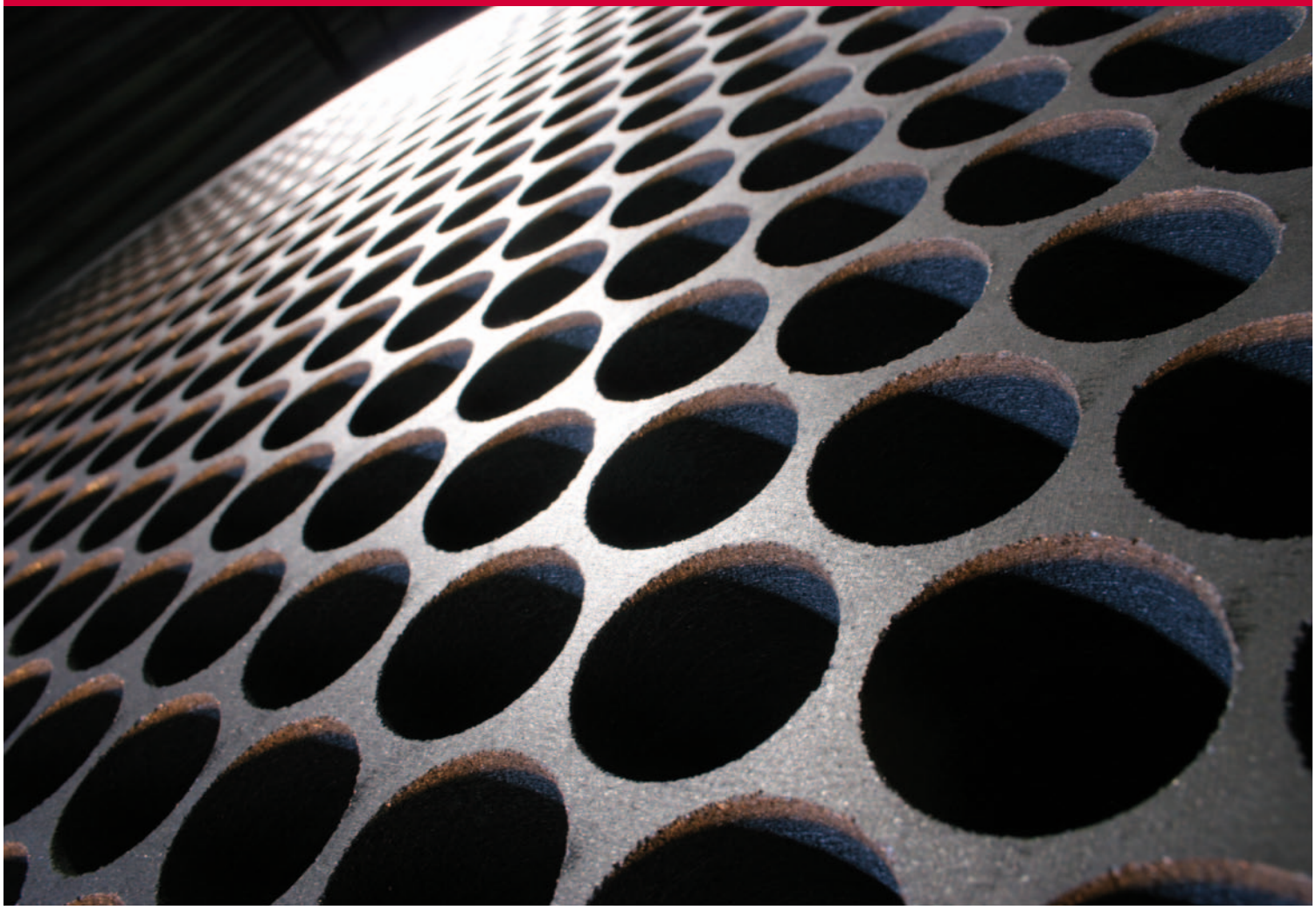
DIABON®

Graphite for
Engineered Process Equipment

Process Technology



Broad Base. Best Solutions.

SGL GROUP
THE CARBON COMPANY

Carbon is Future.

SGL Group – The Carbon Company.

Carbon has unique properties. It is indispensable in the production of steel, aluminum and solar energy systems. Carbon increases the performance of wind turbines and reduces the weight of airplanes, cars and sports equipment.

Carbon substitutes other materials and contributes to a reduction in CO_2 emissions.

SGL Group is one of the leading manufacturers of carbon-based products and has the broadest product and technology portfolio, a global sales network and state-of-the-art production sites in Europe, North America and Asia.

Process Technology

The Business Unit Process Technology is a premium technology provider for chemical and related industry process systems, equipment and after sales services. Our focus are high-tech materials for demanding chemical applications. With smart and sustainable solutions for an increasing number of industry we give proof of our strong innovation culture.

Broad Base

Our range of materials:

- graphite
- SiC
- PTFE
- reactive metals
- steel

Our range of services:

- process design
- engineering
- project management
- production and assembly
- commissioning
- after sales services.

With 9 manufacturing sites in 8 countries and a continually growing worldwide sales and service network, we are always close to our customers.

RELIABILITY.
EFFICIENCY.
SUSTAINABILITY.

Powered by our **Broad Base** of competencies, products and services, we offer **Best Solutions** to our customers. For the Business Unit Process Technology, those solutions are characterized by reliability, efficiency and sustainability.

Best Solutions

▸ Reliability

In a business that strongly depends on reliability we never compromise on quality and safety. Our products deliver dependable results; our services are fast and competent. The long-standing loyalty of our customers proves that we keep our promises – on-time, on-spec, on-budget.

▸ Efficiency

Tailor made, innovative solutions and an integrated approach on chemistry, materials, technology and design, ensure outstanding efficiency and improved customer value: higher yields, lower operating cost, lower service and maintenance cost, longer service intervals and less downtimes, and the extended product lifetime sum up to significant lower total cost of ownership and to a higher return on investment for our customers.

▸ Sustainability

In all industries that deal with resource- and energy- consuming processes sustainability is of crucial importance. Based on innovative solutions, more than 60 % of our sales contribute to the saving of resources and energy and to the reduction of greenhouse gases.

Contents

Criteria for the Use of Graphite
in Chemical Process Equipment Construction

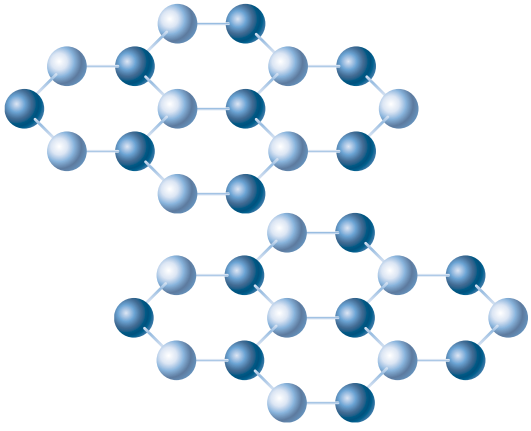
Graphite is a material with ceramic properties. Because of its excellent thermal stability, chemical resistance and high electrical conductivity, it is widely used in electrometallurgy.

Graphite has been employed in chemical process equipment engineering for more than 70 years. In this sector, its applications are determined in the first place by its chemical and physical properties and in the second place by its suitability as a construction material for equipment and pressure vessels.

Cubic DIABON® graphite block

An ideal process equipment material for numerous fields of high-temperature process technology:

- Excellent corrosion resistance
- High thermal conductivity
- Easily machined with standard machine tools
- Simple joining technique by cementing
- Favorable price-performance ratio



We regularly analyze graphite equipment used in chemical production plants, communicate with our customers and focus on research and development work to further improve our graphite materials. This work involves:

- Adjusting the pore volume and pore size to improve strength, corrosion resistance, thermal stability and thermal conductivity
- Ensuring uniform pore distribution, thereby providing a substantial increase in strength values and improved material reliability
- Increasing the stability of graphite components under mechanical load by using carbon fiber reinforcement (DIABON® HF brand)
- Exploiting the good properties of composite materials
- Expanding the application range for graphite components for solids-bearing media by erosion protection measures, e.g. for tube sheets, blocks and pump impellers.

Production of
DIABON® Process Equipment Graphite

Production process for semi-finished graphite products

The production process for graphite requires an extensive amount of time and energy.

Mixing and forming

The raw materials (low-iron petroleum cokes and pitch binders) are mixed at a moderate temperature, forming a homogeneous compound.

Forming by extrusion

Forming by ram extrusion

- Continuous process
- Forming into solid material or tubes

Forming by vibration molding

- Discontinuous process
- Graphite properties non-directional (isotropy)
- Forming by isostatic pressing

View inside a ring furnace chamber

Baking, impregnation and rebaking

The baking process converts the binder pitch to coke, removes most of the volatiles at 1200°C, and leaves a solid, non-deformable carbon body (amorphous carbon). Baking is followed by pitch impregnation and subsequent rebaking to improve density and other properties.

Graphitization plant

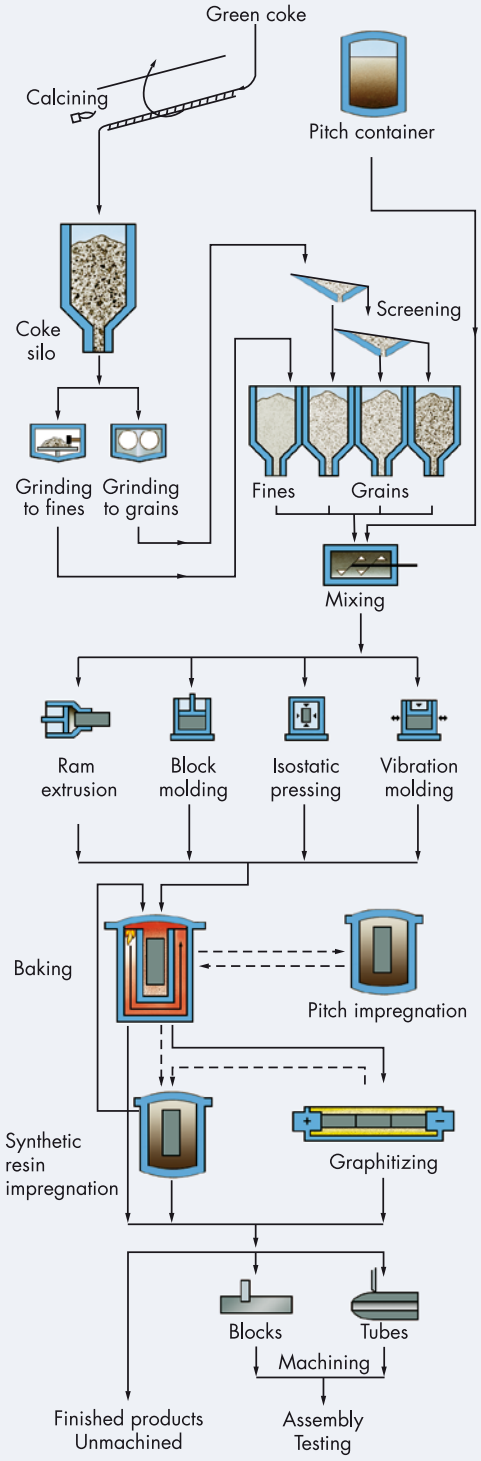
Graphitization

This production step heats the carbon material to a temperature of approx. 3000°C by electricity, inducing the formation of the crystalline graphite structure.

Synthetic resin impregnation by a vacuum-pressure process fills the pores within the graphite, making the material impermeable.

DIABON® plates for heat exchangers

Production process

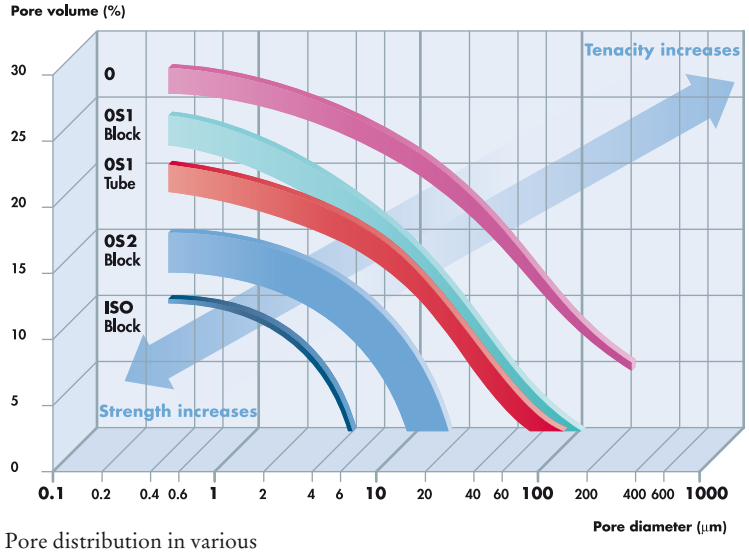


DIABON® Process Equipment Graphite

Characteristic Properties

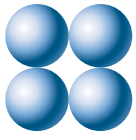
Grain size distribution

▸ Pore distribution, pore volume and pore size are governed mainly by the grain size distribution. They are selected so that optimum base graphite strength is achieved with the poorest possible ceramic properties.



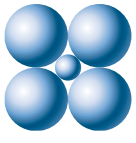
Pore distribution in various graphite brands (%)

▸ Synthetic resin impregnation increases the strength of graphite by a factor of about 2 to 3.



Narrow grain size distribution

▸ Compressive strength of graphite is some 3 to 5 times its tensile strength. This fact is of major significance when graphite is used as a construction material for chemical process equipment.



Optimal grain size distribution

▸ Mechanical strength calculations in graphite process equipment construction are based on specification AD 2000-Merkblatt N2.

Corrosion resistance

Pure carbon and non-impregnated graphite (DIABON 0) display excellent corrosion resistance. Carbon is attacked only by strongly electronegative elements, such as oxygen at temperatures above 500°C and elemental halogens, as well as by powerful oxidizing acids such as nitric and chromic acid.

In the case of impregnated graphite for process equipment, the corrosion resistance is governed essentially by the corrosion and thermal shrinkage behavior of the synthetic resin, as well as by the pore structure of the graphite. Another major factor is the temperature. For this reason it is advisable to consult the resistance tables.

Thermal stability

Non-impregnated graphite can be employed in an inert atmosphere up to 3000°C and in an oxidizing atmosphere up to about 500°C (DIABON 0).
According to specification AD 2000-Merkblatt N2, graphite and carbon are permitted materials for the construction of pressure vessels with wall temperatures between -60°C and +400°C. The following maximum permissible temperatures have been determined for synthetic resin-impregnated graphites by experts of the German Technical Supervisory Board (TÜV):

- ▸ 180°C for DIABON N
- ▸ 200°C for DIABON NS1 and DIABON NS2
- ▸ 140°C for DIABON F100

The material brand is characterized by one letter and three numbers, the latter separated from one another by hyphens, e.g.:

G32-0-200

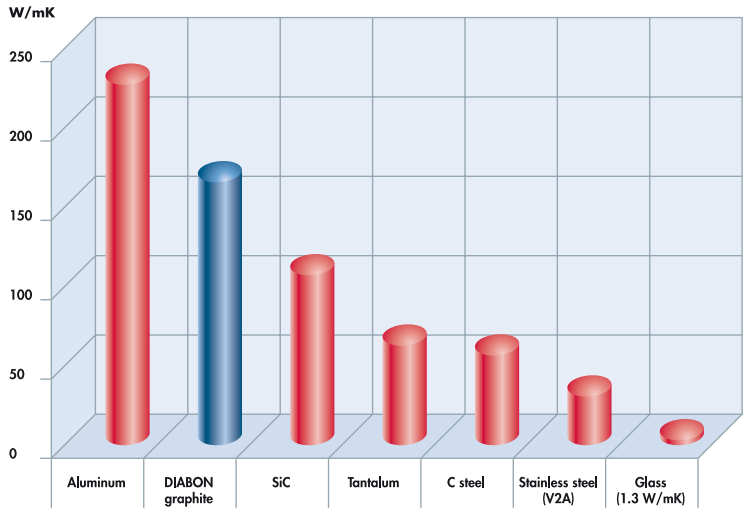
G - for graphite
32 - for tensile strength in N/mm² at 20°C
0 - for decline in strength in ‰ per 10 K temperature increase
200 - for max. permissible material temperature in °C

Thermal conductivity

The thermal conductivity of DIABON graphite at 20°C averages

- 60 to 80 W/mK for tubes and
- 100 to 160 W/mK for blocks.

It is higher than that of many metals. DIABON process equipment graphite is therefore an ideal material for the construction of heat exchangers, combustion furnaces and gas coolers. Synthetic resin impregnation does not impair thermal conductivity.



Thermal conductivity of graphite and other materials
Source: VDI-Wärmeatlas

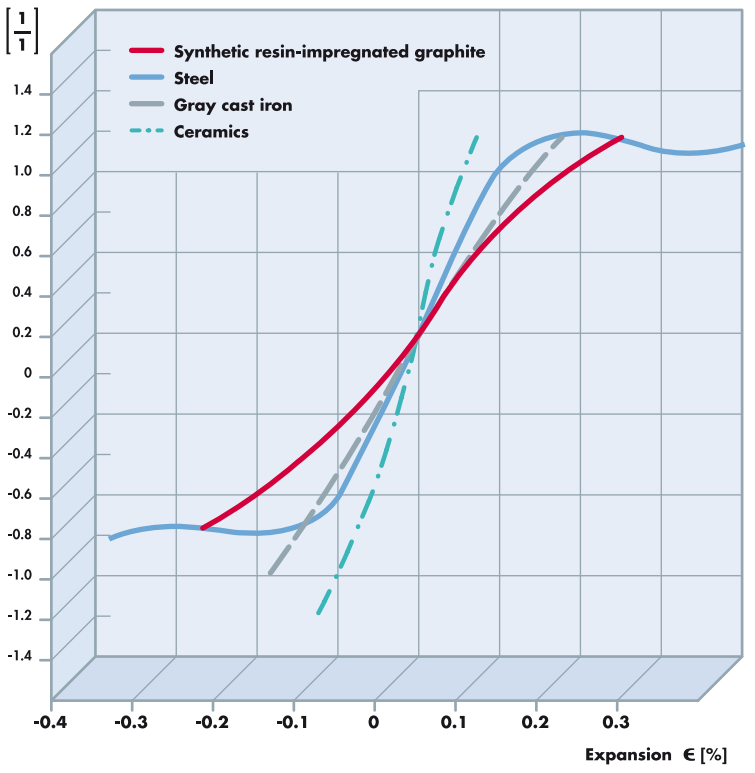
Mechanical strength

The inherent strength of impregnated graphite is governed by the pore size, the pore distribution and other major factors such as the forming operation for blanks and the baking and graphitization process. The vibration molding or isostatic pressing techniques that we use for the forming of blocks impart virtually identical mechanical properties to all blocks, regardless of size.

Compared with vibration-molded material, isographites are noted for their further improved pore distribution, lower pore volume and higher inherent strength values.

Thermal expansion

The coefficient of thermal expansion is governed by the production process and the impregnating resin.

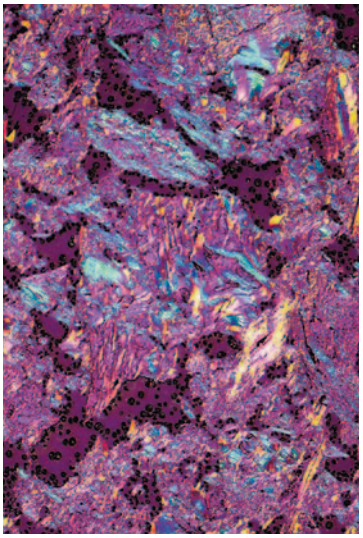


Stress-strain behavior of graphite and other materials

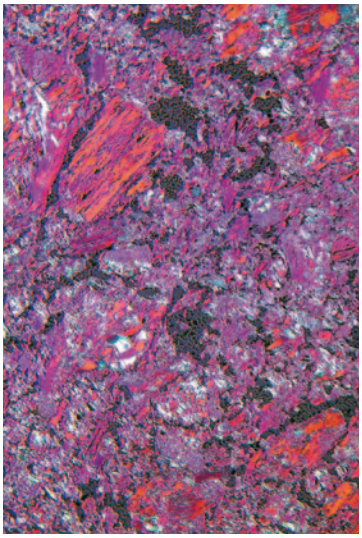
Permeability

As a result of SGL Group's optimum synthetic resin impregnation in combination with the base material employed, the graphite brands used for DIABON equipment have high impermeability, not merely as a short-term property in new equipment but also in continuous plant operation.

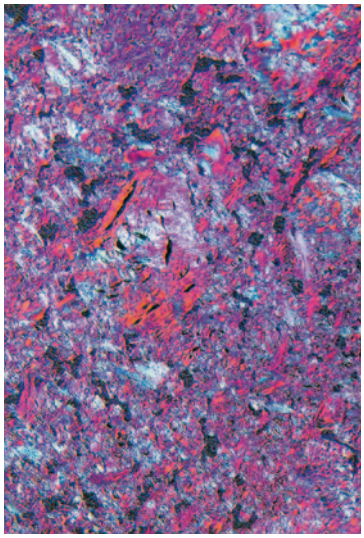
Properties and Uses
of DIABON® Graphite Brands



Micrograph of DIABON® N



Micrograph of DIABON® NS1



Micrograph of DIABON® NS2

DIABON® N

Properties
Synthetic resin-impregnated impermeable graphite material. Maximum permissible service temperature 180°C under most process conditions.

Applications
Components subjected to low mechanical and thermal stresses.

DIABON® NS1

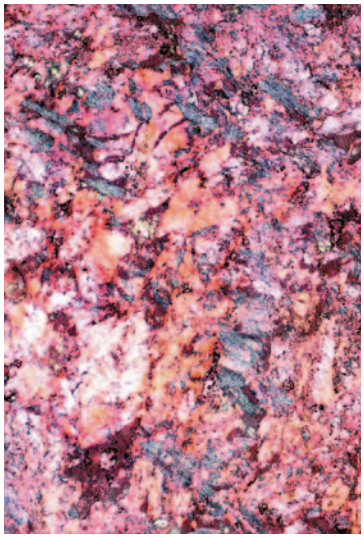
Properties
Standard material for a wide range of applications in chemical technology, environmental protection and similar industries. DIABON NS1 is an impermeable, synthetic resin-impregnated process equipment graphite with a highly homogeneous material structure. This results in greater corrosion resistance and thermal stability. Maximum permissible material temperature is 200°C.

Applications
Standard material for the production of heat exchangers and hydrogen chloride synthesis plants, as well as for all other pressure- and temperature-stressed components.

DIABON® NS2

Properties
Graphite material for superior demands. This graphite brand is distinguished by its lower pore volume combined with reduced pore size and greater mechanical strength. Maximum permissible material temperature is 200°C.

Applications
DIABON NS2 is suitable for heat exchanger blocks, tubes and tube sheets, if these are subjected to elevated mechanical stress and/or extremely corrosive media and solvents.



Micrograph of DIABON® CT

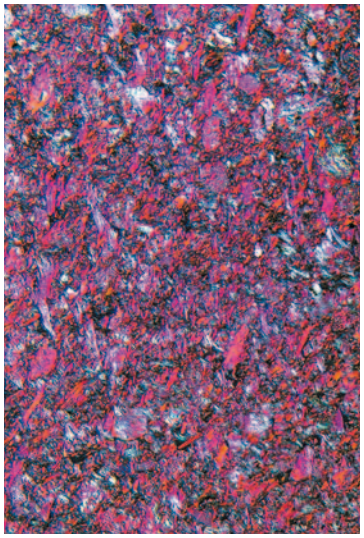
DIABON® CT

Properties

DIABON CT is an impermeable, PTFE-impregnated process equipment graphite with a highly homogeneous structure. Maximum permissible material temperature is 200°C. Best suited for oxidizing and alkaline media.

Applications

Blocks for block heat exchangers, in particular for stainless steel pickling lines and the pharmaceutical industry.



Micrograph of DIABON® F100

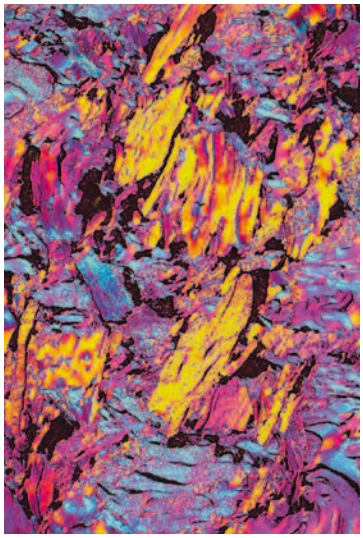
DIABON® F100

Properties

Fluoroplastic-bonded graphite with an extremely high graphite content of over 80 % and a highly homogeneous structure. A special advantage of this material is its increased corrosion resistance in oxidizing media. Owing to the anti-adhesive properties of fluoroplastic, DIABON F100 has an extremely low tendency to fouling and incrustation of surfaces. The high surface bonding strength makes this composite material best suited for use in abrasive media. Maximum permissible material temperature is 140°C.

Applications

Plates for plate heat exchangers, also for processes involving oxidizing acid mixtures.



Micrograph of DURABON®

DURABON®

Properties

DURABON baked carbon differs from DIABON graphite mainly in its low thermal conductivity (4 to 6 W/mK) and great hardness. Compared with graphite, its tensile and flexural strength values are some 20 % higher and its compressive strength is 50 % higher.

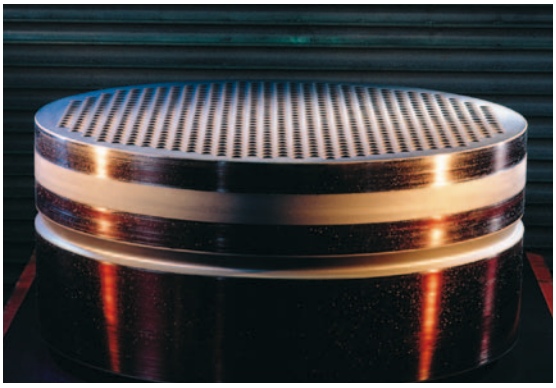
Applications

Like graphite, DURABON hard burned carbon is rendered impermeable by resin impregnation. In this impermeable form, it is used in the construction of thermally insulating, corrosion-resistant linings for columns and vessels, as well as for abrasion-resistant pump components.

Carbon Fiber-Reinforced Components
for Increased Safety

In developing the carbon fiber reinforcement of components (DIABON NS1▸HF1 and DIABON NS2▸HF2), SGL Group has found a way to increase the operational reliability of DIABON graphite components appreciably and expand their range of application under high-stress conditions. The fiber reinforcement is used for tube sheets, headers and column sections, but in particular for tubes.

The DIABON HF tube is a DIABON NS tube around which highly pretensioned fibers are wound like a net. The specific behavior of the carbon fiber ensures that the pretensioning of the reinforcement is retained even under sharply fluctuating load or stress surges. Owing to the carbon fiber's negative coefficient of thermal expansion, the bursting pressure and leakage resistance pressure are greater at higher temperatures than room temperature.



Carbon fiber-reinforced tube sheet

DIABON® HF tubes

Properties of graphite tubes with carbon fiber reinforcement

▸ Increased bursting pressure

The tube becomes more resistant to steam hammer and service pressures above the permitted limit, its bursting pressure at room temperature being raised to 130 to 140 % of that of a non-reinforced tube, depending on the tube dimensions.

▸ Resistance of a cracked tube to leakage

Should a longitudinal crack occur in a DIABON HF tube as a result of overstressing, the tube will not allow any major leakage up to a differential pressure of some 2 to 5 bar. In all instances, the reinforcement prevents any spalling from the tube and a consequent escape of product in large quantities. Usually, the equipment can continue in operation without interruption until the next planned shutdown.

Comparison of properties

37/25 diam. format	Unit	DIABON NS1	DIABON HF1	Comparison
Bursting pressure at 20°C	bar	80	110	137.5 %
Bursting pressure at 50°C	bar	75	120	160.0 %
Resistance to pressure surges	relative	1.0	2.5	250.0 %

Abrasive Wear Protection
for Heat Exchangers and Pumps

In chemical processes involving corrosive media and high velocities, damage due to erosion may occur if the products have a high solids content.

Tube sheet with wear sleeves

DURABON® impeller

Heat exchangers

▸ The tube sheet inlet areas in shell and tube heat exchangers are protected against erosion by wear sleeves cemented in the tube sheet passages.

▸ In block heat exchangers, a hard-wearing oxide ceramic coating of both end faces and the flow passage inlet zone allows the blocks to be effectively protected against wear.

Pumps

▸ The pump impeller and pump volute case can be ceramic oxide-coated; alternatively, the impeller can be manufactured from DURABON.

Characteristic Properties
of DIABON® Process Equipment Graphite

Block brand							
Property (guide values)	Unit	DIABON N	DIABON NS1	DIABON NS2	DIABON CT	DIABON F100	DURABON
Max. service temperature	°C	180	200	200	200	140	200
Bulk density	g/cm³	1.85-1.90	1.88-1.92	1.88-1.92	1.90-1.92	2.05	1.88-1.92
Dyn. modulus of elasticity	MPa	15-20•10³	15-20•10³	15-20•10³	15-20•10³	>13•10³	15-20•10³
Flexural strength	MPa	20-25	25-35	30-40	25-30	>47	25-35
Compressive strength	MPa	40-50	60-80	60-80	50-60	80-100	60-80
Tensile strength	MPa	>16	>18	>20	>18	28	>18
Lin. coefficient of thermal expansion (20 - 200°C)	K⁻¹•10⁶	4-6	8-10	8-10	8-10	(20-140°C) 35	8-10
Thermal conductivity	W/mK	>120	>120	>140	>140	>20	>5
Coefficient of permeability	cm²/s	10⁻⁵	10⁻⁶	10⁻⁶	10⁻⁶	10⁻⁶	10⁻⁶
Ash content	vol. %	< 0.5	< 0.5	< 0.5	< 0.5	–	< 0.5

Tube brand					
Property (guide values)	Unit	DIABON NS1	DIABON HF1	DIABON NS2	DIABON HF2
Max. service temperature	°C	200	200	200	200
Bulk density	g/cm³	> 1.93	> 1.93	> 1.90	> 1.90
Dyn. modulus of elasticity	MPa	25-27•10³	25-27•10³	25-27•10³	25-27•10³
Flexural strength	MPa	> 52	> 52	> 60	> 60
Compressive strength	MPa	> 85	> 85	> 90	> 90
Tensile strength	MPa	> 28	–	> 30	–
Lin. coefficient of thermal expansion (20 - 200°C)	K⁻¹•10⁶	4-5	4-5	4-5	4-5
Thermal conductivity	W/mK	> 60	50	> 60	50
Coefficient of permeability	cm²/s	10⁻⁶	10⁻⁶	10⁻⁶	10⁻⁶
Ash content	vol. %	< 0.5	< 0.5	< 0.5	< 0.5
Bursting pressure	bar	80-100	100-110	80-100	100-110

Corrosion Resistance
of DIABON® Process Equipment Graphite

Based on their aggressiveness to DIABON, the media are divided into three groups:

Group A

Media to which DIABON graphite is resistant at all concentrations and up to the permitted material temperature.

Group B

Media to which DIABON graphite is resistant only up to certain concentrations and temperatures.

Group C

Media on which our material specialists should be consulted.

The corrosion tables enable statements to be made on the resistance of DIABON graphite to aggressive media and its suitability for process equipment construction.

The concentration data apply to aqueous solutions. If organic compounds are used, the data apply to pure substances. The corrosion resistance limits apply at normal pressure and take no account of any phase changes.

Users of mixtures (especially mixtures with impurities) should request our advice, since the corrosive properties of mixtures may deviate substantially from the properties of pure substances. Statements are, however, made without guarantee. In cases of doubt, especially where exposure to various substances, together or successively, is concerned, corrosion tests should be conducted in the actual plant in question with the original media, if this is possible. Subsequently, a careful investigation of samples in our laboratories reveals whether the material tested can be classified as resistant, or not.

Group A

Media to which DIABON graphite is resistant at all concentrations and up to the permitted material temperature.

Inorganic substances

Acids
- Arsenic acid
- Boric acid
- Hydrobromic acid
- Hydrochloric acid
- Hydrofluosilicic acid
- Phosphoric acid
- Sulfurous acid

Salt solutions (aqueous)
- Acetates
- Chlorides
- Fluorides
- Nitrites
- Sulfates
- Sulfites

Miscellaneous substances
- Carbon disulfide
- Hydrogen bromide, gaseous
- Hydrogen chloride, gaseous
- Hydrogen sulfide
- Phosgene (anhydrous)
- Phosphorus oxychloride
- Sodium thiosulfate
- Sulfur dioxide, gaseous
- Thionyl chloride

Organic substances

Aliphatic hydrocarbons
- Heptane
- Hexane
- Kerosene
- Mineral oil
- Naphtha
- Pentane
- Petrol / gasoline
- Synthetic petrol / gasoline

Aromatic hydrocarbons
- Benzene
- Toluene
- Xylene

Halogenated hydrocarbons
- Allyl chloride
- Carbon tetrachloride
- Chlorobenzene
- Dibromoethane
- Dichlorobenzene
- Dichloroethane
- Dichloroethylene
- Dichloromethane
- Ethyl chloride
- Ethylene chlorohydrine
- Tetrachloroethylene
- Vinyl chloride

Alcohols, thioalcohols (mercaptans), phenols
- Amyl acolhol
- Butanol
- Ethanol
- Glycol
- Glycerine
- Methanol
- Octanol
- Phenol
- Propanol

Ethers
- Diethyl ether
- Dimethyl ether
- Isopropyl ether

Amines, nitro compounds, nitriles (CN compounds)
- Aniline
- Aniline hydrochloride
- Cyanogen chloride
- Cyanuric chloride
- Dimethyl aniline
- Nitrobenzene
- Nitrotoluene
- p-Nitrochlorobenzene

Aldehydes, ketones
- Acetaldehyde
- Acetone
- Chloral
- Chloral hydrate
- Formaldehyde
- Glyoxal
- Paraldehyde

Carboxylic acids
- Acetic acid
- Acrylic acid
- Benzoic acid
- Butyric acid
- Caprylic acid
- Chloroacetic acid (mono-, di-, tri-)
- Citric acid
- Dichloropropionic acid
- Formic acid
- Fumaric acid/ maleic acid
- Glycolic acid
- Lactic acid
- Linoleic acid
- Malic acid
- Nicotinic acid
- Oleic acid
- Palmitic acid
- Propionic acid
- Salicylic acid
- Stearic acid
- Tannic acid
- Tartaric acid

Esters
- Butyl acetate
- Butyl acrylate
- Ethyl acetate
- Isopropyl acetate
- Vinyl acetate
- Acetic acid esters

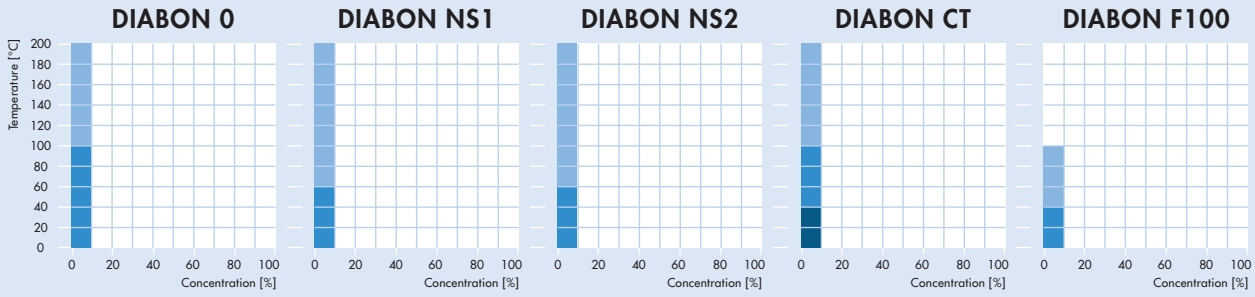
Miscellaneous compounds
- Amino acids, such as folic acid
- Carboxylic acid anydrides, such as acetic acid anhydride
- Organic sulfonic acids, such as benzene-sulfonic acid
- Toluene-sulfonic acid

Group B

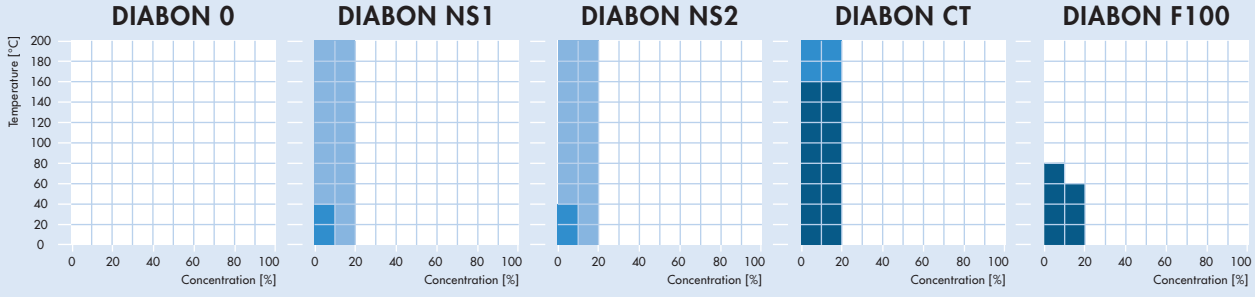
Media to which DIABON graphite is resistant only up to certain concentrations and temperatures.

Typical corrosion resistance to:

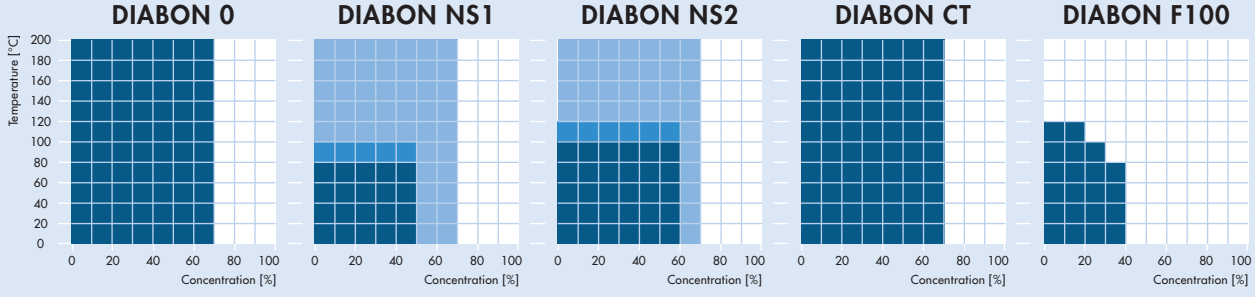
Sodium hypochlorite / NaOCl



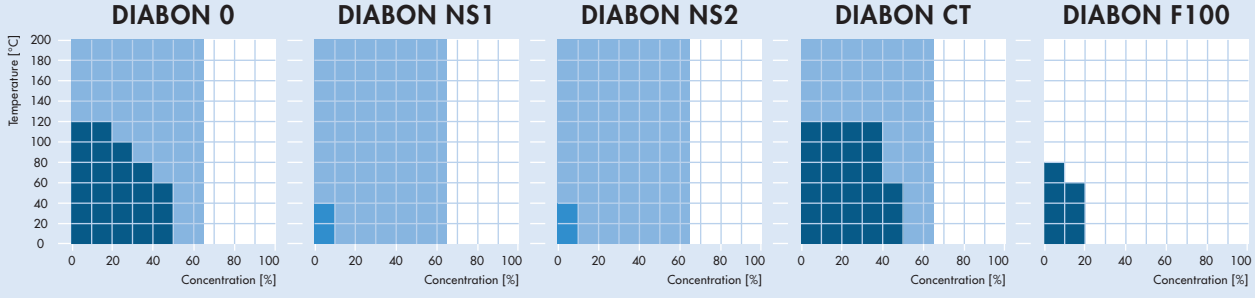
Pickling liquors / HNO_3 + HF 5 %



Hydrofluoric acid / HF



Nitric acid / HNO_3



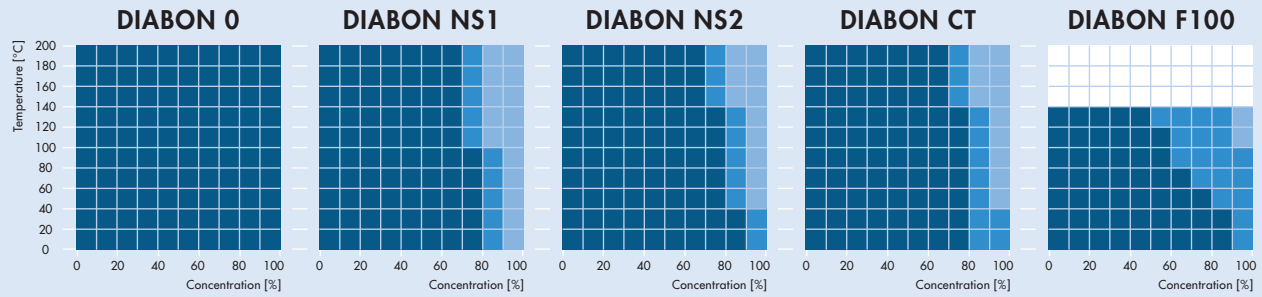
Fully resistant | Partially resistant | Not resistant | No information available

Group B

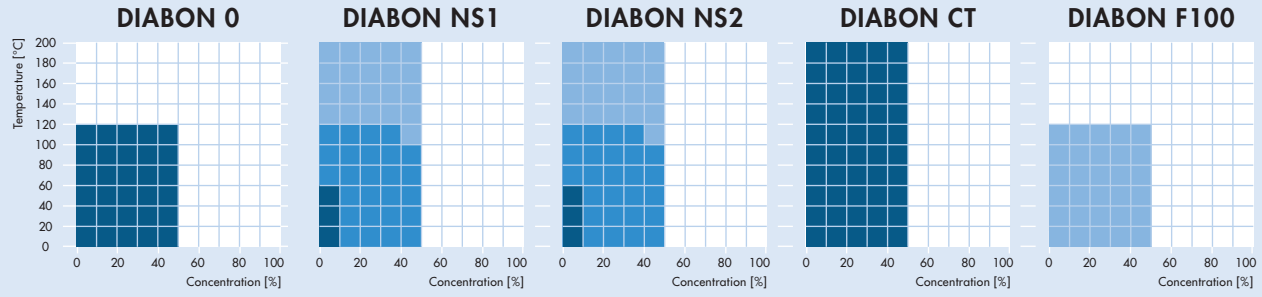
Media to which DIABON graphite is resistant only up to certain concentrations and temperatures.

Typical corrosion resistance to:

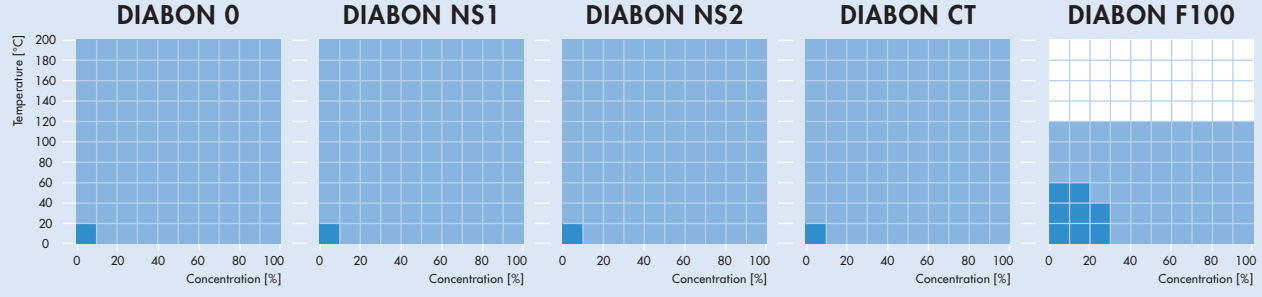
Sulfuric acid / H_2SO_4

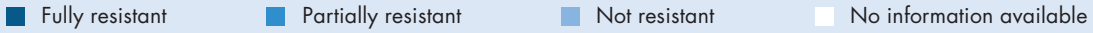


Caustic soda solution / NaOH



Chromic acid / H_2CrO_4





We'll be glad to send you our complete corrosion resistance table on request.

Group C

Media to which DIABON graphite is only partially resistant, if at all.

Production process

Oxidizing acids
- Chlorosulfonic acid
- Oleum

Acid mixtures
- Aqua regia
- Nitric acid/hydrochloric acid > 20 %
- Nitric acid/hydrofluoric acid > 20 %

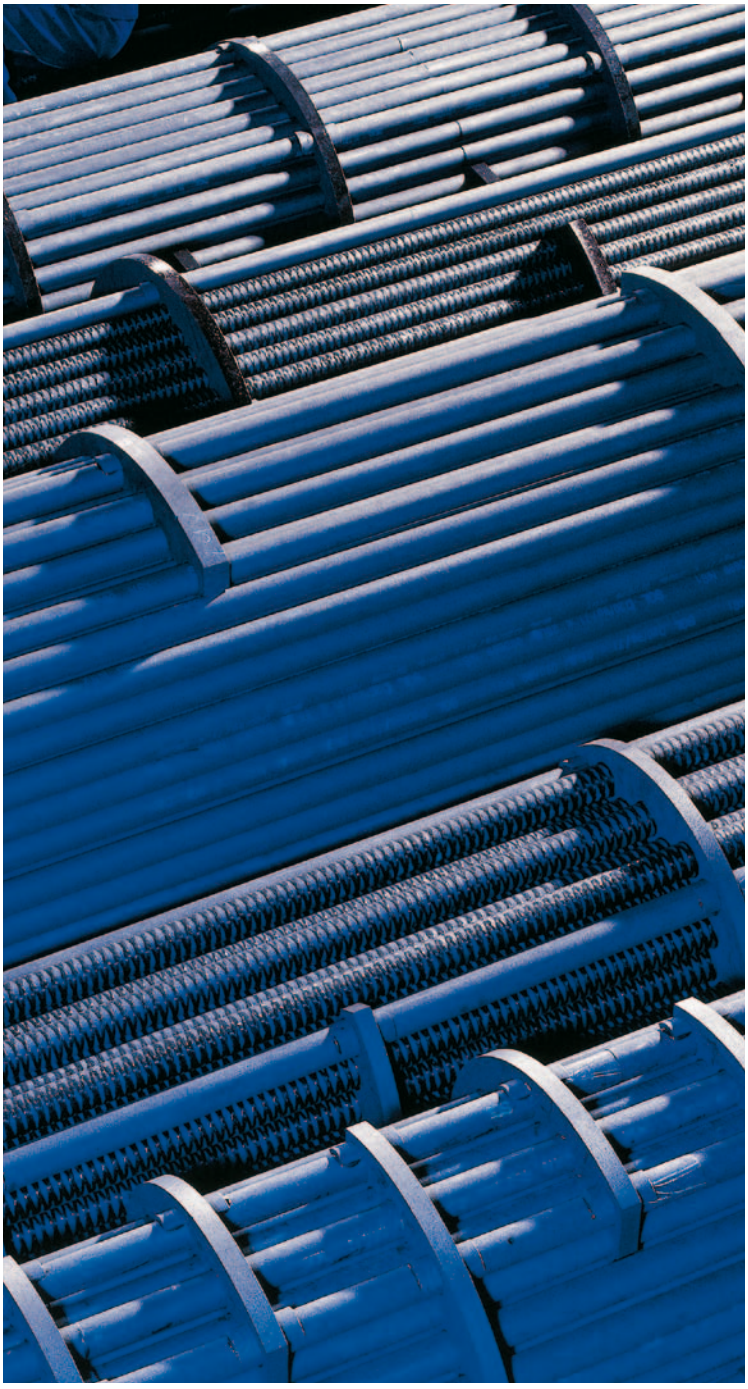
Free halogens
- Bromine, bromine water
- Chlorine, moist, and chlorine-water solution
- Fluorine
- Iodine

Bleach liquors
- Calcium hypochlorite
- Sodium hypochlorite

Alkalis
- Caustic potash solution > 10 %
- Caustic sodium solution > 10 %

Organic solvents
- Dimethylformamide
- Dioxane
- Tetrahydrofurane

Please consult our materials specialists.



DIABON® tube bundles with and without carbon fiber reinforcement

Quality Management
and After Sales Service

Quality Management

Continuous quality assurance is an integral part of the SGL Group corporate philosophy.

Our quality management system is certified in accordance with ISO 9001:2008. In order to guarantee consistently high quality to our customers, we work according to a key performance indicator orientated quality management system.

Depending on specifications we are able to meet specific requirements like the Pressure Equipment Directive 97/23/EC Annex III, Module H/H1, AD 2000 Merkblatt N2 as well as ASME "U" Stamp, Section VIII, Part UIG.

After Sales Services –
Anytime and Everywhere

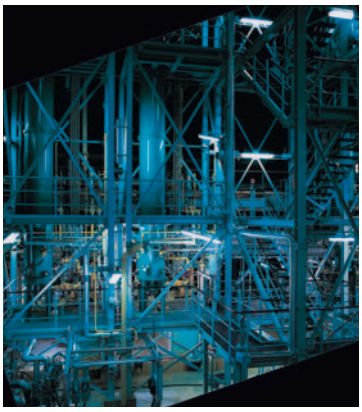
We take care of our products during the entire operational lifetime. We aim to provide the best customer service anytime and everywhere.

- Maintenance – genuine spare parts supply, failure analysis, repair, field service
- Fast emergency support
- Start-up assistance
- Consulting for continuous improvement

Our service specialists as well as our service centers work in a global network to support you best.

Process Technology

Our Products



System Solutions

- Syntheses
- Distillation and concentration
- Purification
- Dilution
- Absorption
- Desorption
- Thermal destruction and recycling
- Reactors and converters
- Heat storage
- ...

Equipment Solutions

- Graphite and SiC heat exchangers – shell & tube, block and plate type
- Columns and internals
- Vessels
- Quenchers
- Pumps
- Rupture discs
- PTFE piping and bellows
- PTFE hoses
- ...

After Sales Services

- Maintenance
- Emergency support
- Start-up assistance
- Consulting
- ...

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