SIGRAFLEX®

Products Manufactured from
Flexible Graphite Foil

Expanded Graphite

Broad Base. Best Solutions.

SGL GROUP
THE CARBON COMPANY

Contents

SGL Group – The Carbon Company – is one of the world's leading manufacturers of carbon-based products. Our comprehensive portfolio ranges from carbon and graphite products to carbon fibers and composites.

Due to their unique properties, carbon and graphite are indispensable materials for many industries, such as the steel, aluminum, semiconductor, energy, automotive, aerospace, sporting goods, chemical and environmental protection industries.

Many decades of experience in handling carbon materials of all kinds and also intensive development work have enabled us to optimize our manufacturing processes at our global production sites in Europe, North America and Asia.

SGL EXCELLENCE

We constantly aim to improve our products and services to meet our customers' specific requirements. Our company-wide SGL Excellence Initiative and Six Sigma, which we apply as core methods, are state-of-the-art tools for bringing continuous improvement to all areas, including our processes, engineering know-how, product development and innovation, as well as the expertise of our workforce. We keep in close contact with our customers, suppliers and logistic partners to help achieve this.

SEALING PRODUCTS MADE FROM EXPANDED NATURAL GRAPHITE

Our Business Line Expanded Graphite manufactures flexible graphite foils and graphite sealing sheets from expanded graphite. They are marketed under the SIGRAFLEX® trademark to the automotive and industrial sealing industry worldwide. SIGRAFLEX is available in all major industrialized countries. All standard SIGRAFLEX products are available from stock.

We carry out constant product monitoring using non-destructive methods during manufacturing operations and also conduct random checks involving specified analytical processes. Needless to say that our quality management system is certified under the relevant standards.

Thanks to their high quality, our products can be used even in the most demanding applications. By offering products of guaranteed quality, we can enter into long-term cooperation agreements in a spirit of mutual trust.

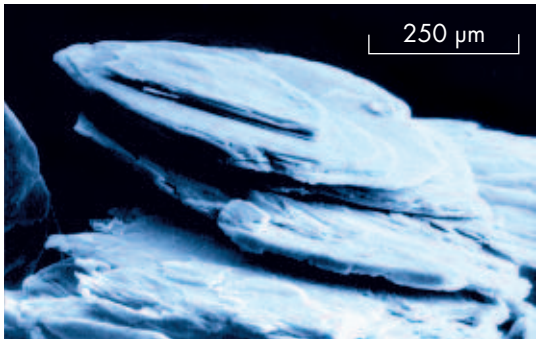
Our technical and marketing staff maintain close contacts with the company's customers, such as plant constructors and operators of complex plants in the chemical and petrochemical industries, power stations and foundries. Besides choosing the right products for particular applications, they are also available to carry out the design calculations for seals.

SIGRAFLEX® sealing sheets and gaskets

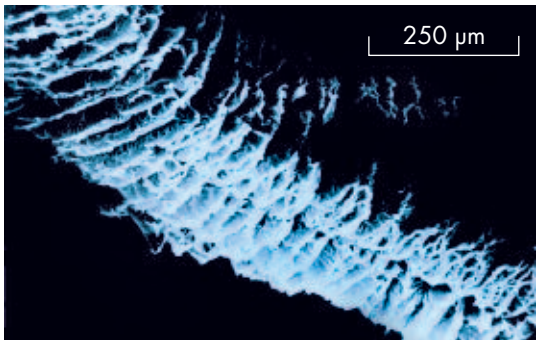
SIGRAFLEX® Sealing Products for a Clean Environment

Sabic Polyolefine GmbH production plant at the Gelsenkirchen site

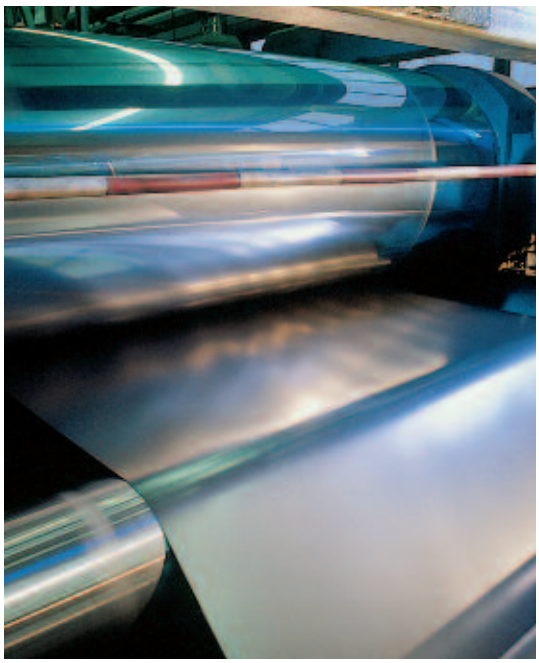
PRODUCTION AND CHARACTERISTIC PROPERTIES



Natural graphite flake



Expanded graphite "worm"



Flexible graphite foil

The raw material used in the production of SIGRAFLEX is natural graphite flake with well-ordered crystalline structures. We select the highest-quality raw materials from the various grades available around the world. Graphite intercalation compounds are produced from the natural graphite flakes. The thermal decomposition (expansion) of these compounds leads to the formation of loose "worms" of pure graphite, which are compressed into foils without binder or filler. The resulting alignment of the graphite particles and their planar structures produces a high degree of directional dependence (anisotropy) in the properties. The high purity of SIGRAFLEX derives from the raw materials used, as well as from the quality of the mechanical, chemical and thermal purification processes.

Graphite sheets are manufactured in various forms, namely unreinforced, impregnated or reinforced. A distinction is made between sheets reinforced with perforated sheet steel and those using smooth stainless steel foil reinforcement. The special impregnation of our sheets ensures scratch resistance, antistick behavior, greater strength and lower gas permeability.

Characteristic Properties

- Low permeability to gases and liquids
- Flexibility, soft texture
- Resistance to most media
- Absence of health hazard; asbestos-free
- Environmental compatibility
- Suitability for use at temperatures ranging from -250°C up to approx. 3000°C depending on installation and service conditions:
  – in an inert atmosphere up to approx. 800°C (limits imposed by metal reinforcement to be observed)
  – for applications in air at more than approx. 400°C, users should request our advice
- Absence of binders means no ageing or embrittlement
- Long-term stability of compressibility and recovery over a wide temperature range
- No cold or warm flow up to maximum permissible gasket pressure
- High residual stress
- Properties highly anisotropic, particularly in respect of electrical and thermal conductivity
- Resistance to radiation
- Very good resistance to thermal shock
- Ease of cutting or punching

PRODUCT DESIGNATIONS

Typical product designation

SIGRAFLEX V 200 10 C 2 I

Type

F	Foil
L	Sheet
V	Reinforced sheet

Thickness in hundredths of a mm

Bulk density of graphite in tenths of g/cm³

Ash content

Z	≤ 0.15 %
E	≤ 1.00 %
C	≤ 2.00 %
D	≤ 4.00 %
APX	≤ 2.00 % advanced antioxidation technology

Reinforcements (in V types only)

1	0.2 mm perforated steel sheet, DIN material no. 1.0330
2	0.1 mm perforated stainless steel sheet, ASTM material no. 316 (L)
3	0.05 mm stainless steel foil, ASTM material no. 316 (L), unbonded
4	0.05 mm stainless steel foil, ASTM material no. 316 (L), bonded

For other reinforced materials, users should request our advice

Upgrading

E	Sheet type EMAIL
I	Impregnation
S	Self-adhesive finish
X	Corrosion inhibitor
I-P	TA Luft (German Clean Air Act) grades

Product Overview

Table 1

Product	Type	Thickness [mm]	Width [m]	Length [m]	Graphite bulk density [g/cm³]
Rolls*)					
SIGRAFLEX FOIL	F.....C	0.35 to 1.0	0.5/1.0	50/100	0.7 to 1.3
	F.....D	0.35 to 1.0	0.5/1.0	50/100	0.7 to 1.3
	F.....E	0.35 to 1.0	0.5/1.0	50/100	0.7 to 1.3
	F.....APX	0.1 to 1.0	0.5/1.0	50/100	0.7 to 1.3
	F.....Z	0.1 to 1.0	0.5/1.0	50/100	0.7 to 1.3
	F.....ZX	0.5	0.5	50	0.7
	F.....CS/ZS	0.5/1.0	0.5	25/50	1.0
Sheet					
SIGRAFLEX BASIS	L.....Z	1.0/1.5/2.0	1.0	1.0	1.0
	L.....C	1.0/1.5/2.0	1.0	1.0	1.0
	Homogeneous, free of adhesives and binders				
Impregnated sheet					
SIGRAFLEX STANDARD	L.....CI impregnated	1.0/1.5/2.0	1.0	1.0	1.0
	Homogeneous, free of adhesives and binders				
Reinforced sheets					
SIGRAFLEX ECONOMY	V.....C4	0.5 to 3.0	1.0	1.0	1.0
	Stainless steel foil reinforcement, 316 (L), 0.05 mm, bonded				
SIGRAFLEX UNIVERSAL	V.....C2I impregnated	1.5/2.0/3.0	1.0/1.5	1.0/1.5	1.0
	Perforated stainless steel sheet reinforcement, 316 (L), 0.1 mm, unbonded				
SIGRAFLEX HOCHDRUCK	V.....Z3I impregnated	1.0 to 4.0	1.0/1.5	1.0/1.5	1.1
	Multiple stainless steel foil reinforcement, 316 (L), 0.05 mm, unbonded				
SIGRAFLEX EMAIL	V.....Z3E	2.0/3.0	1.0	1.0	1.1
	Two stainless steel foil reinforcements, 316 (L), 0.05 mm, unbonded				
SIGRAFLEX UNIVERSAL *PRO*	V.....C2I-P impregnated	1.6/2.0/3.0	1.0/1.5	1.0/1.5	1.0
	Perforated stainless steel sheet reinforcement, 316 (L), 0.1 mm, unbonded				
SIGRAFLEX SELECT	V16010C3I	1.6	Gaskets with inner eyelet		1.1
	Two stainless steel foil reinforcements, 316 (L), 0.05 mm, unbonded				
SIGRAFLEX HOCHDRUCK *PRO*	V.....Z3I-P impregnated	1.5 to 4.0	1.0/1.5	1.0/1.5	1.1
	Multiple stainless steel foil reinforcement, 316 (L), 0.05 mm, unbonded				
SIGRAFLEX MF	V.....Z2MF	1.6/2.0/3.0	1.0	1.0	1.1
	Perforated stainless steel sheet reinforcement, 316 (L), 0.1 mm, unbonded				

Other dimensions, densities and reinforcements on request

*) Foil tapes are available at ≥ 4.0 mm width

SIGRAFLEX FOIL
Characteristic data for a graphite bulk density of 1.0 g/cm³

Table 2

Product type		F.....10Z
Permeability coefficient for air through plane (DIN 51925)	cm^2/s	$< 5 \cdot 10^{-5}$
Thermal stability		Can be used from -250°C up to approx. 3000°C (in protective gas)
Sublimation temperature	°C	> 3000
Ash content (DIN 51903)	%	≤ 0.15
Chloride content (DIN 28090-2)	ppm	≤ 10
Tensile strength	N/mm^2	≥ 4
Elongation at break	%	≥ 1
Residual stress (DIN 52913)	N/mm^2	≥ 48
Specific heat (20°C)	kJ/(kg · K)	0.7
Coefficient of thermal expansion (20 to 1000°C)		
in plane	$10^{-6}/K$	approx. 1
through plane	$10^{-6}/K$	approx. 30
Shore hardness (D)		approx. 30
Coefficient of friction at 20°C in air against steel, peak-to-valley height ≤10 µm		0.1

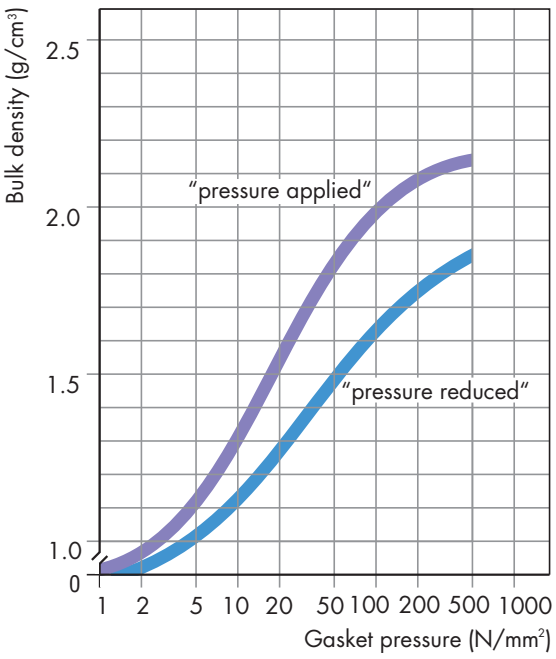


Fig. 1:

Bulk density of SIGRAFLEX with an initial bulk density of 1.0 g/cm³ as a function of the gasket pressure applied at a specific time ("pressure applied") and that applied previously ("pressure reduced")

MECHANICAL AND PHYSICAL PROPERTIES OF SIGRAFLEX FOILS

SIGRAFLEX products are available with standard bulk densities of 0.7 to 1.3 g/cm³. The change in bulk density as a function of the pressure applied in the compression process is shown in Figure 1. Deformation consists of two distinct components, namely:

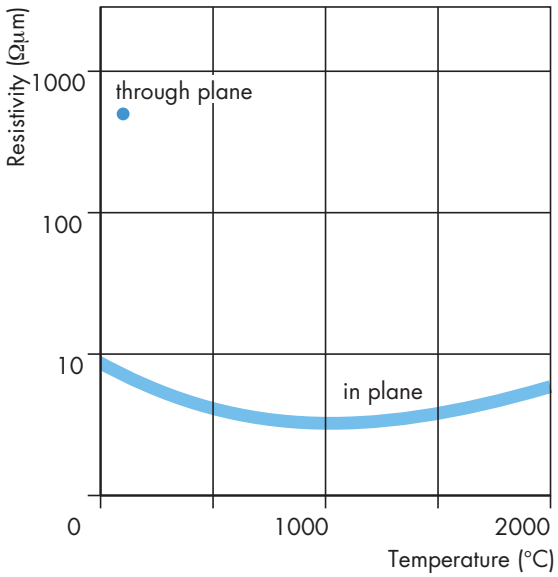
- irreversible or plastic deformation and
- reversible or elastic deformation.

The curve marked "pressure reduced" in Figure 1 describes the irreversible deformation of SIGRAFLEX FOIL. The difference in density between the lines marked "pressure applied" and "pressure reduced" is due to the elastic deformation component. This component is of overriding importance in the sealing action of the graphite foil, for example. As the degree of compression rises, the individual graphite crystals are increasingly oriented within the plane of the sheet. As a result, the anisotropy of the properties becomes more pronounced: see Figures 2 to 5.

In Table 2, the properties of the high-purity foil F.....10Z are illustrated by way of example from the large number of foil types available. A more detailed description is given in the data sheet SIGRAFLEX® FOIL.

The thermal stability of graphite foil has a great impact on the reliability and service life of seals made of it. Figure 10 shows the improved oxidation resistance of SIGRAFLEX APX foil compared with commercially available graphite grades.

OTHER PHYSICAL PROPERTIES



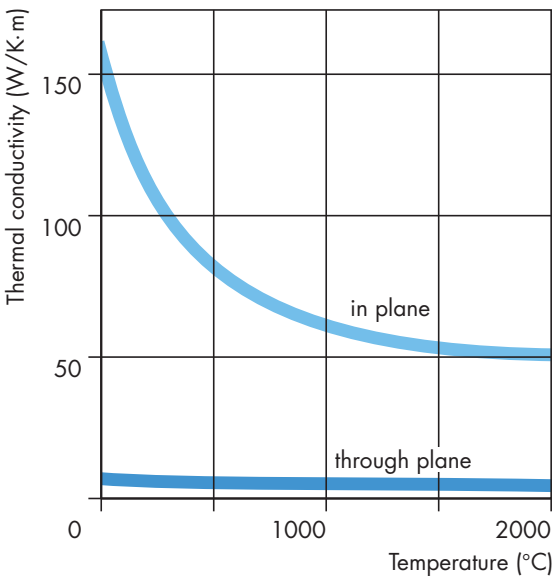
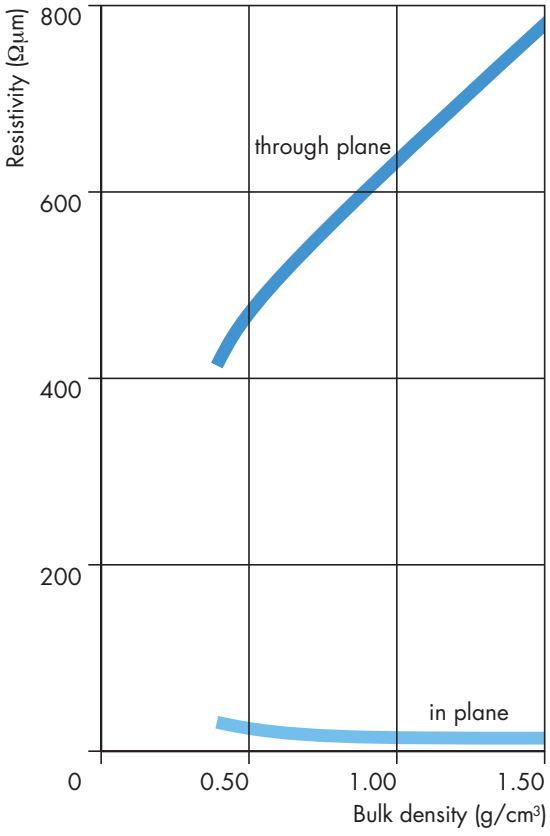


Fig. 2:

Resistivity as a function of temperature, bulk density 1.0 g/cm³

Fig. 3:

Thermal conductivity as a function of temperature, bulk density 1.0 g/cm³



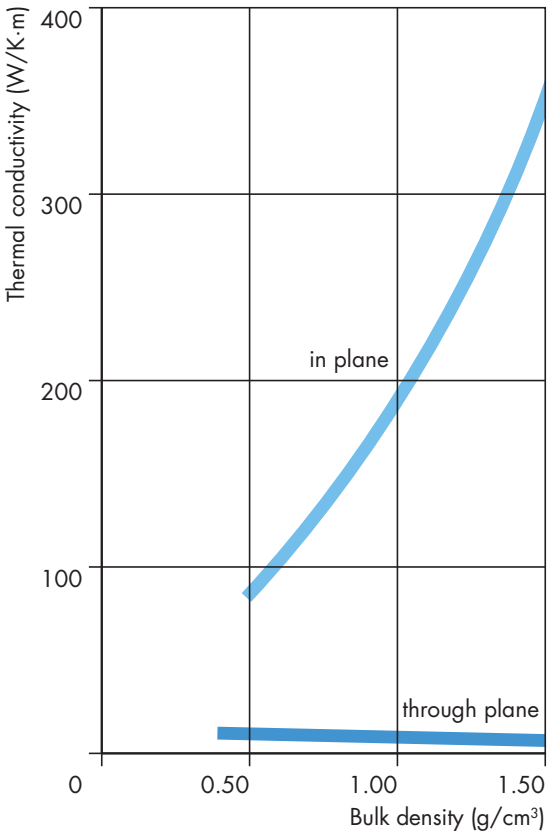


Fig. 4:

Resistivity as a function of bulk density

Fig. 5:

Thermal conductivity as a function of bulk density

MECHANICAL AND PHYSICAL PROPERTIES OF UNREINFORCED SIGRAFLEX SHEETS

The SIGRAFLEX BASIS sheets containing no additives or reinforcements and bearing the designations L.....C and L.....Z have the same properties as foils F.....C and F.....Z. Guideline material data on SIGRAFLEX BASIS and SIGRAFLEX STANDARD (impregnated) are contained in Table 3. Impregnated sheets differ from unimpregnated sheets in having better impermeability, better handling properties and antistick surfaces.

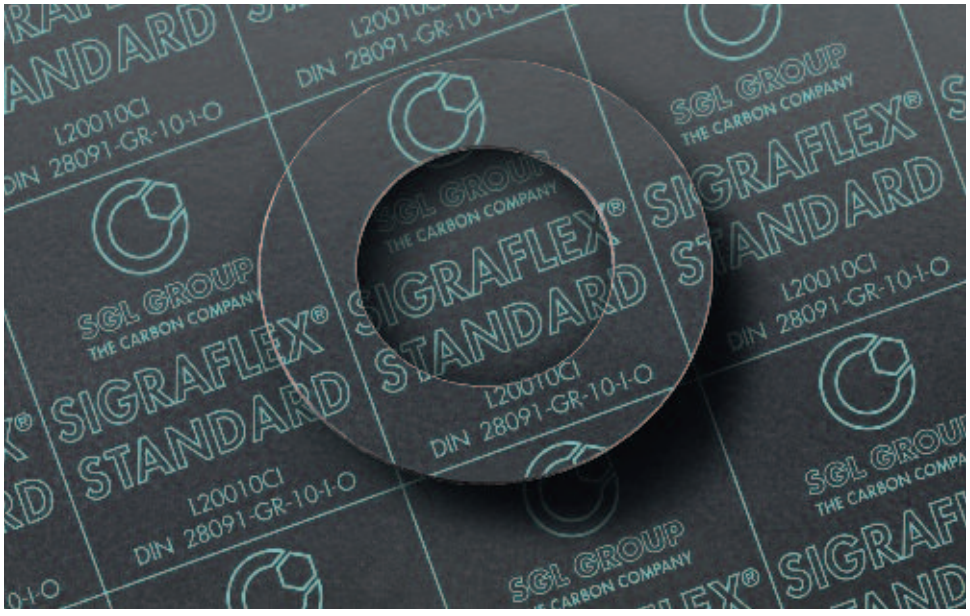
Figure 6 shows the compression behavior of SIGRAFLEX BASIS with a bulk density of 1.0 g/cm^3 and a material thickness of 2.0 mm. A distinction has to be drawn between the curve branches "under pressure" (line k) and "after reduction in pressure" (linies r). Depending on the pressure applied beforehand, the material recovers along one of the "r" lines after the pressure is reduced.

Typical levels of recovery are 10 % of the residual thickness after previous compressive stress (for bulk density of 1.0 g/cm^3). If the bulk density is higher, the percentage recovery decreases.

The "recovery" is synonymous with the "elastic deformation" of the material. The difference between the initial thickness of the material and its thickness after reduction in pressure is its "plastic deformation". Both values are plotted in Figure 7 under conditions of increasing gasket pressure for a material having a bulk density of 1.0 g/cm^3 and containing no additives.

Compared with other sealing materials, SIGRAFLEX is soft and relatively easy to compress. This enables the material to adapt well to the sealing surface, for instance. Over long service periods SIGRAFLEX displays no notable changes in its properties compared with other sealing materials. Figure 8 shows the decline in gasket pressure in various sealing materials during their service life. Figure 9 shows typical leakage rate curves of various materials.

Disparities in compression have an effect on the material's impermeability. The leakage rate declines at high gasket pressure when the installed SIGRAFLEX gaskets have a high bulk density in their compressed state. One major advantage of this material is that the sealing effect is retained even when the gasket pressure is reduced.



Unreinforced SIGRAFLEX sheets. Characteristic data for 2.0 mm thick sheets *Table 3*

Product type			STANDARD L20010CI	BASIS L20010Z
Graphite, bulk density		g/cm³	1.0	1.0
Graphite, ash content (DIN 51903)		%	≤ 2.0	≤ 0.15
Chloride content (DIN 28090-2)		ppm	≤ 50	≤ 20
Compression factors [1], [2] (DIN 28090-2)				
• Compressibility at 20°C	ε_{KSW}	%	40 to 50	40 to 50
• Recovery at 20°C	ε_{KRW}	%	3 to 5	3 to 4
• Hot creep during operation	ε_{WSW}	%	< 4	< 3
• Recovery at 300°C	ε_{WRW}	%	3 to 4	3 to 4
Compressibility (ASTM F36A-66)		%	40 to 50	40 to 50
Recovery (ASTM F36A-66)		%	10 to 15	10 to 15

(1) ε_{KSW} Gasket compression set under a pressure of 35 N/mm²
ε_{KRW} Gasket recovery after reduction in pressure from 35 N/mm² to 1 N/mm²
ε_{WSW} Gasket creep compression under a pressure of 50 N/mm² at 300°C after 16 h
ε_{WRW} Recovery after reduction in pressure from 50 N/mm² to 1 N/mm²
The percentage changes in thickness of ε_{KSW}, ε_{KRW}, ε_{WSW} and ε_{WRW} are relative to the initial thickness of the gasket

(2) Gasket factors in accordance with DIN E 2505, DIN 28090, DIN 52913 and DIN EN 13555 for the various sheet materials can be found in our separate product data sheets

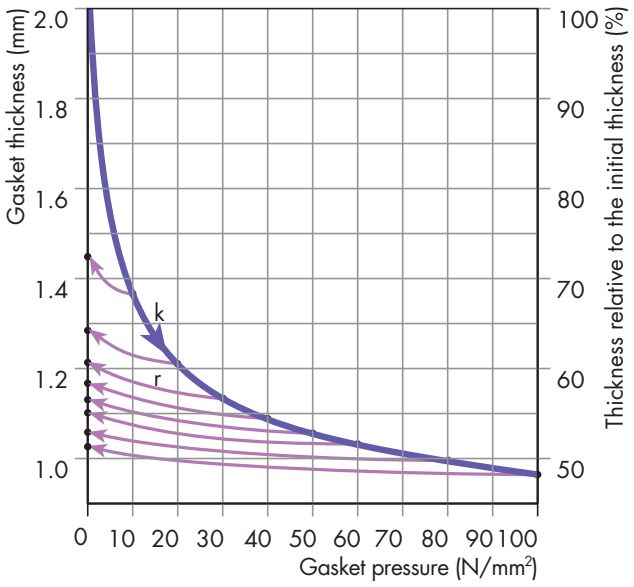


Fig. 6:

Compression curve k and recovery curves r as determined on gaskets)*

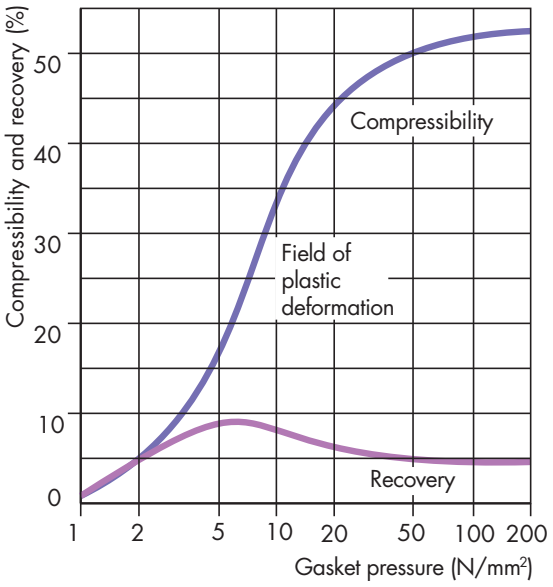


Fig. 7:

Recovery as a percentage of the initial thickness of SIGRAFLEX gaskets) plotted against preceding gasket pressure (plastic deformation = compressibility - recovery)*

**) SIGRAFLEX BASIS L20010Z*

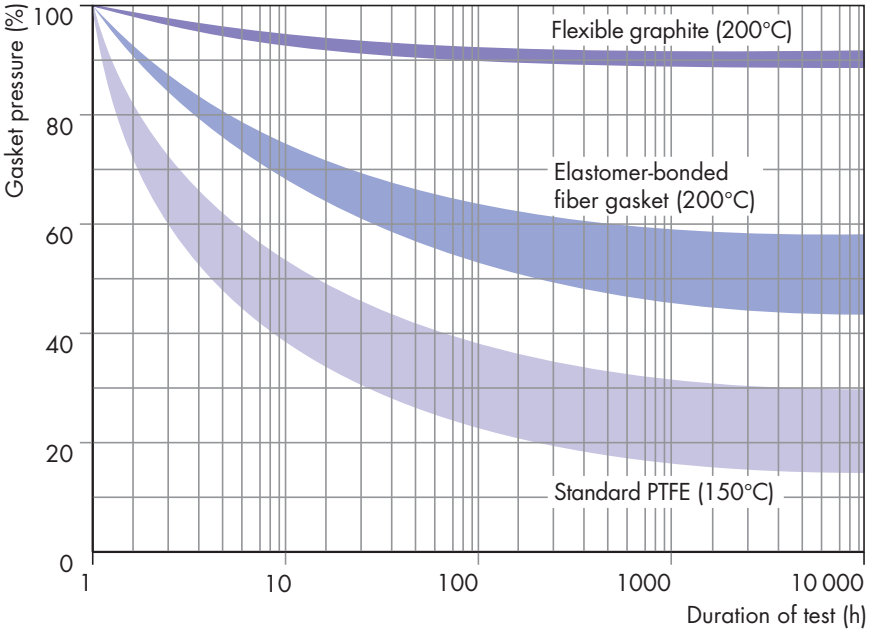
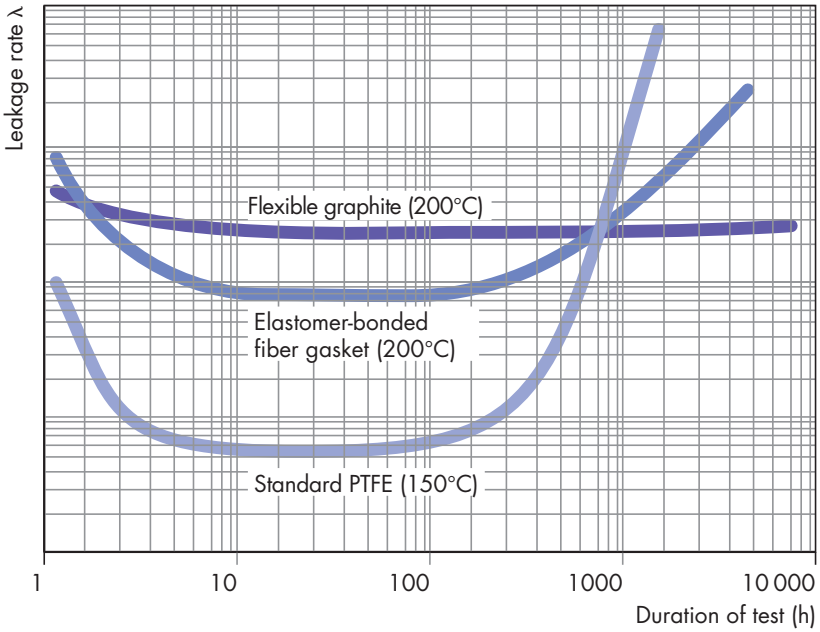


Fig. 8:

Change in the gasket pressure of various sealing materials during long-term testing, measured in accordance with DIN 28090-1 in flange PN 40 DN 40. The testing temperature for this material was set at only 150°C. The flexible graphite retains its high residual stress even after exposure to load for approximately 1 year

Fig. 9:

Change in the leakage rate of various sealing materials in long-term testing, measured in accordance with DIN 28090-1 and -2 in flange PN 40 DN 40. The testing temperature for this material was set at only 150°C owing to the hot flow of PTFE



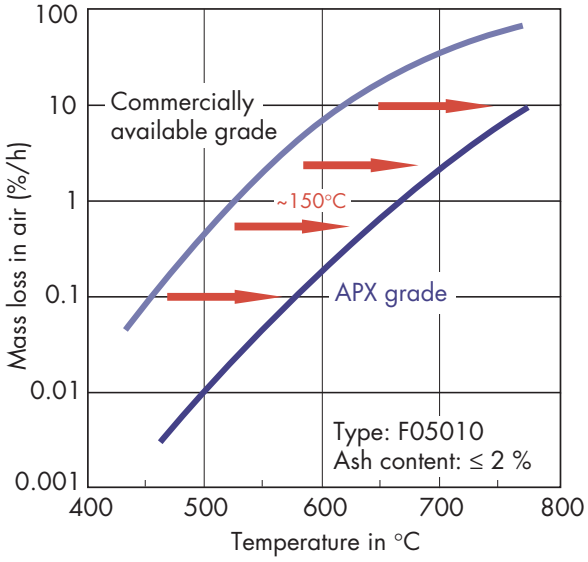


Fig. 10:

Comparison between the thermal stability of a commercially available graphite foil and that of SIGRAFLEX APX foil with advanced oxidation resistance

MECHANICAL AND PHYSICAL PROPERTIES OF REINFORCED SIGRAFLEX SHEETS

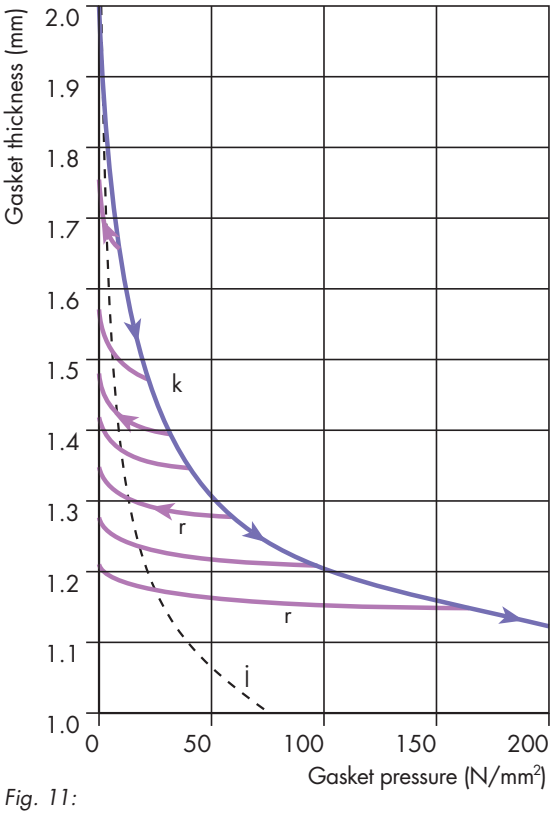


Fig. 11:

Compression curve k and various recovery curves r as determined on gaskets fabricated from SIGRAFLEX HOCHDRUCK V20011Z3I. For purposes of comparison, the compression line j for SIGRAFLEX BASIS is included from Figure 6

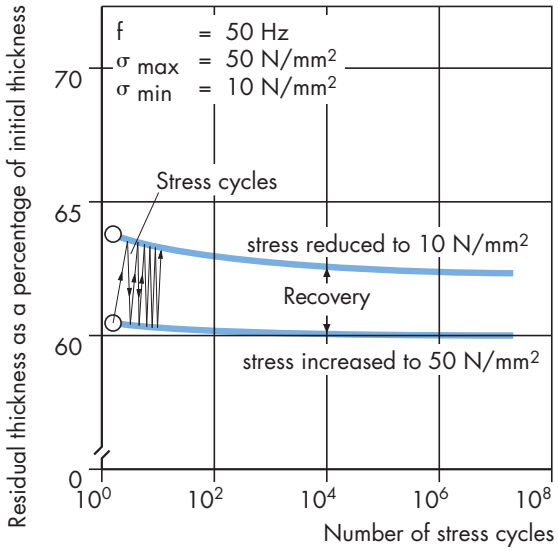


Fig. 12:

Behavior of SIGRAFLEX UNIVERSAL under vibrating stress

Reinforced sheets of various versions are illustrated in Figure 14. Typical data on these sheets are compared in Table 4. The minimum requirements specified in DIN 28091-4 are surpassed by sheets with metal reinforcement. Detailed particulars are given in the relevant data sheets. The maximum permissible gasket pressures on reinforced sheets are illustrated in Figure 13. With gaskets it is important to note the width-to-thickness ratio; as it increases, so too does the maximum permitted pressure. The curves shown by way of example are for materials 2 mm thick.

Figure 11 shows the typical compressibility and recovery of SIGRAFLEX HOCHDRUCK for reinforced sheet types in comparison with those of unreinforced sheets.

SIGRAFLEX has an extraordinary stability in vibrating machinery. This is illustrated by the following example: A gasket pressure of 50 N/mm² reduces the initial thickness of SIGRAFLEX UNIVERSAL by about 60 %. After this preliminary stress the material is subjected to vibrating stresses ranging from 10 to 50 N/mm². Its power of recovery is retained even after 10^7 stress alternation cycles, when no more than very slight creep compression is observed (see Figure 12).

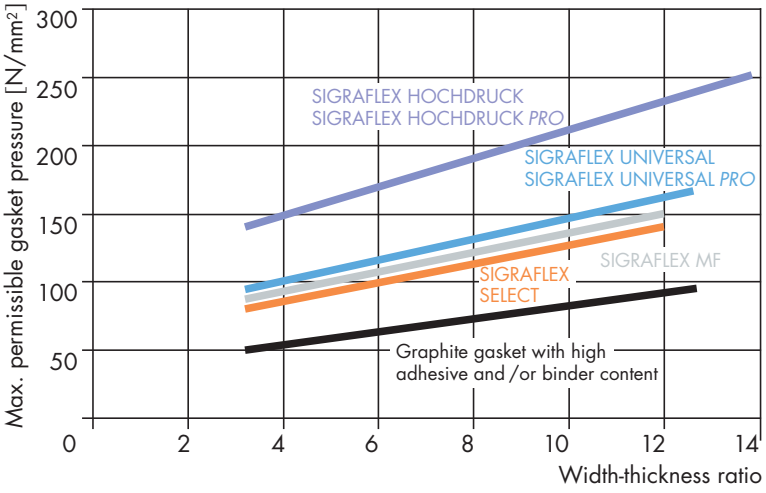


Fig. 13:

Max. permissible gasket pressure for gaskets made from reinforced SIGRAFLEX sheets of 2 mm thickness, as determined at 300°C in accordance with DIN 28090-1

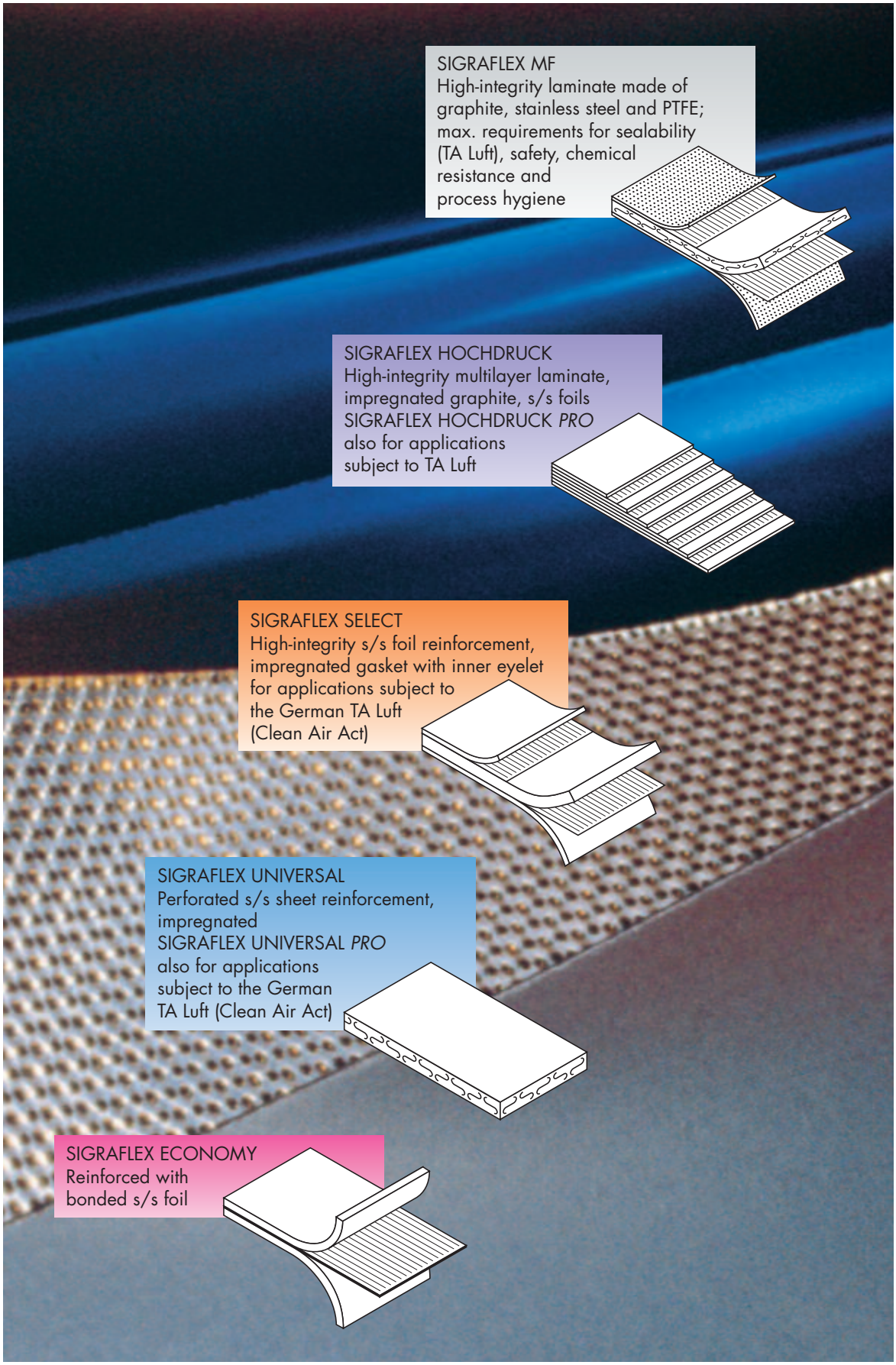


Fig. 14:

Sketches showing the construction of sheets reinforced with metal foils

The flexible graphite is shown in white color. The metal foils are shown as hatched surfaces. The PTFE foils are shown as dotted surfaces.

Reinforced SIGRAFLEX sheets. Characteristic data for 2.0 mm thick sheets[*)] *Table 4*

Product type			ECONOMY V20010C4	UNIVERSAL V20010C2I UNIVERSAL *PRO* V20010C2I-P	SELECT V16010C3I	HOCHDRUCK V20011Z3I HOCHDRUCK *PRO* V20011Z3I-P	MF V20011Z2MF
Graphite, bulk density		g/cm^3	1.0	1.0	1.0	1.1	1.1
Graphite, ash content (DIN 51903)		%	≤ 2.0	≤ 2.0	≤ 2.0	≤ 0.15	≤ 0.15
Chloride content (DIN 28090-2)		ppm	≤ 50	≤ 50	≤ 50	≤ 20	≤ 20
Reinforcing sheet, number			1	1	2	3	1
Reinforcing sheet, thickness		mm	0.05	0.1	0.05	0.05	0.1
Reinforcing sheet, type			smooth	perforated	smooth	smooth	perforated
Reinforcing sheet, ASTM material no.			316(L)	316(L)	316(L)	316(L)	316(L)
Compression factors [(1), (2)] (DIN 28090-2)							
• Compressibilty at 20°C	ε_{KSW}	%	35 to 45	35 to 45	30 to 40	30 to 40	25 to 35
• Recovery at 20°C	ε_{KRW}	%	3.5 to 4.5	4 to 6	3 to 5	4 to 5	3 to 5
• Hot dreep during operation	ε_{WSW}	%	< 5	< 5	< 2	< 4	< 4
• Recovery at 300°C	ε_{WRW}	%	3 to 4	3 to 6	2 to 4	3 to 4	3 to 5
Compressibility (ASTM F36A-66)		%	40 to 50	30 to 45	30 to 40	30 to 40	25 to 35
Recovery (ASTM F36A-66)		%	10 to 15	15 to 25	10 to 15	15 to 20	15 to 20

(1) ε_{KSW} Gasket compression set under a pressure of 35 N/mm^2
ε_{KRW} Gasket recovery after reduction in pressure from 35 N/mm^2 to 1 N/mm^2
ε_{WSW} Gasket creep compression under a pressure of 50 N/mm^2 at 300°C after 16 h
ε_{WRW} Recovery after reduction in pressure from 50 N/mm^2 to 1 N/mm^2
The percentage changes in thickness of ε_{KSW}, ε_{KRW}, ε_{WSW} and ε_{WRW} are relative to the initial thickness of the gasket
(2) Gasket factors in accordance with DIN E 2505, DIN 28090, DIN 52913 and DIN EN13555 for the various sheet materials can be found in our separate product data sheets
*) SIGRAFLEX SELECT in 1.6 mm thickness

APPROVALS AND CERTIFICATES

The technical world we live in is growing increasingly complex. To minimize risks, standards are being agreed on both national and international levels and statutory regulations issued.

For many years our materials have been subjected to wide-ranging tests as specified in the current regulations. The respective product reports, approvals and certificates are listed below. SIGRAFLEX materials comply with many different standards and statutory regulations. This represents a safeguard for our customers.

- **BAM[1] reports** on tests conducted to determine reactivity with gaseous and liquid oxygen.
  SIGRAFLEX FOIL
  SIGRAFLEX STANDARD
  SIGRAFLEX ECONOMY
  SIGRAFLEX UNIVERSAL
  SIGRAFLEX UNIVERSAL *PRO*
  SIGRAFLEX SELECT
  SIGRAFLEX HOCHDRUCK
  SIGRAFLEX HOCHDRUCK *PRO*
  SIGRAFLEX MF

- **BAM reports**
  on tests conducted to determine the chemical stability of ethylene oxide and propylene oxide.
  SIGRAFLEX UNIVERSAL
  SIGRAFLEX HOCHDRUCK

- **Blow-out resistance (TÜV)**
  SIGRAFLEX UNIVERSAL
  SIGRAFLEX UNIVERSAL *PRO*
  SIGRAFLEX SELECT
  SIGRAFLEX HOCHDRUCK
  SIGRAFLEX HOCHDRUCK *PRO*
  SIGRAFLEX MF

- **DVGW[2] registration reports for gas supply**
  SIGRAFLEX FOIL
  SIGRAFLEX STANDARD
  SIGRAFLEX ECONOMY
  SIGRAFLEX UNIVERSAL
  SIGRAFLEX UNIVERSAL *PRO*
  SIGRAFLEX SELECT
  SIGRAFLEX HOCHDRUCK
  SIGRAFLEX HOCHDRUCK *PRO*
  SIGRAFLEX MF

- **DVGW test certificates for drinking water in accordance with KTW[3]**
  SIGRAFLEX FOIL
  SIGRAFLEX STANDARD

- **Fire safety (API 607 and/ or BS 6755-2)**
  SIGRAFLEX UNIVERSAL
  SIGRAFLEX UNIVERSAL *PRO*
  SIGRAFLEX SELECT
  SIGRAFLEX HOCHDRUCK
  SIGRAFLEX HOCHDRUCK *PRO*
  SIGRAFLEX MF

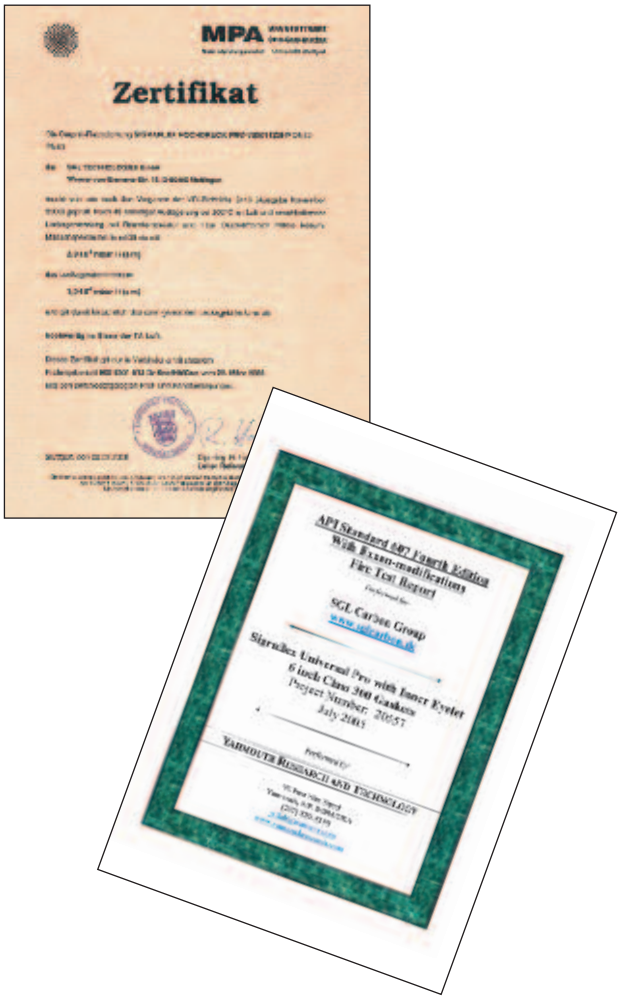
- **Germanischer Lloyd**
  SIGRAFLEX UNIVERSAL
  SIGRAFLEX HOCHDRUCK

- **TA Luft (VDI 2440) (German Clean Air Act)**
  SIGRAFLEX UNIVERSAL *PRO*
  SIGRAFLEX SELECT
  SIGRAFLEX HOCHDRUCK*[*)]*
  SIGRAFLEX HOCHDRUCK *PRO*
  SIGRAFLEX MF

- **Test report of the Baden-Württemberg Department of Industry**
  Office for Chemical and Technical Testing: Contact of SIGRAFLEX graphite foil with foodstuffs

- **TRD 401 (manhole gaskets)**
  SIGRAFLEX HOCHDRUCK

- **United States Coast Guard**
  SIGRAFLEX UNIVERSAL
  SIGRAFLEX HOCHDRUCK



1) BAM = Bundesanstalt für Materialprüfung (Federal Institute for Materials Testing), Berlin

2) DVGW = Deutscher Verein der Gas- und Wasserfachmänner (German Association of Gas and Water Operatives)

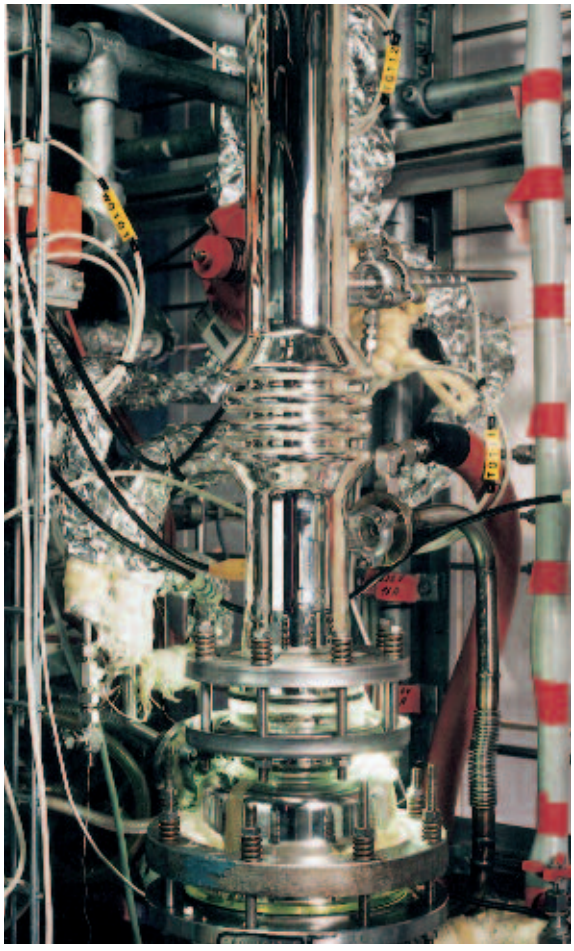
3) KTW = Kunststoff-Trinkwasser-empfehlung des Bundesgesundheits-ministeriums (Federal German Ministry of Health recommendation for max. levels of plastics in drinking water)

*) For raised-face flanges with inner eyelet, for tonque-and-groove flanges without inner eyelet

CHEMICAL RESISTANCE OF SIGRAFLEX

Based on natural graphite, SIGRAFLEX products are resistant to most media up to high temperatures.

Unreinforced SIGRAFLEX is resistant to inorganic and organic acids and bases, solvents, waxes and oils, but not to agents with a powerful oxidizing action, such as highly concentrated nitric acid, highly concentrated sulfuric acid (oleum), nitrating acid and chloric acid, or molten salts with a powerful oxidizing action. Where no details of concentration and temperatures are given for the media listed, it can be assumed that the concentration is 100 % and that the temperature is boiling point or melting point.



The data given in Table 5 should always be checked by the user since the limits to the use of SIGRAFLEX seals also depend on the design features, internal pressure, temperature and the gasket pressure. Resistance to highly aggressive substances not listed needs to be ascertained. SIGRAFLEX users should request advice from us in such circumstances.

The resistance of reinforced SIGRAFLEX gaskets is usually governed by the reinforcing metal sheets or foils used. Table 5 makes no reference to the stability values for steel or PTFE. The stainless steel with ASTM material no. 316 (L) used in unbonded SIGRAFLEX sheets (UNIVERSAL, UNIVERSAL *PRO*, SELECT, HOCHDRUCK, HOCHDRUCK *PRO* and EMAIL) has proved very successful in the chemical industry because of its good stability. Upon request we also provide a list of chemical media showing the resistance of graphite foil, stainless steel and PTFE. On bonded sheets (ECONOMY) particular attention must be paid to the stability of the adhesive, especially at elevated temperatures.

As is the case with other gasket materials, it is essential for chemical stability tests on SIGRAFLEX to be carried out with the material in a compressed state (see DIN 28090-3).

Chemical resistance of SIGRAFLEX FOIL (pure graphite)***)

Table 5

Alcohols
e.g.
- ● Ethyl alcohol
- ● Glycol
- ● Isopropyl alcohol
- ● Methyl alcohol

Aldehydes
e.g.
- ● Acetaldehyde
- ● Benzaldehyde
- ● Formaldehyde

Ethers
e.g.
- ● Diethyl ether
- ● Dioxane
- ● Diphenyl ether
- ● Methyl ethyl ether

Esters
e.g.
- ● Acetic acid amyl ester
- ● Acrylic acid ethyl ester
- ● Ethyl butyl ester

Ketones
e.g.
- ● Acetone
- ● Ethyl methyl ketone
- ● Methyl isobutyl ketone

Hydrocarbons
e.g.
- ● Benzene
- ● Ethylene
- ● Iso-octane
- ● Propane
- ● Propylene
- ● Styrene
- ● Xylene

Halogenated hydrocarbons
e.g.
- ● Carbon tetrachloride
- ● Chlorobenzene
- ● Chloroform
- ● Frigen products

Organic acids
e.g.
- ● Acetic acid
- ● Acrylic acid
- ● Formic acid
- ● Hexachlorphenyl acetic acid
- ● Maleic acid
- ● Monochloroacetic acid
- ● Phenylacetic acid
- ● Phthalic acid
- ● Stearic acid
- ● Sulfonic acid
- ● Tartaric acid
- ● Trichloroacetic acid

Amines
e.g.
- ● Aniline
- ● Diethylamine
- ● Triethylaminoethanol

Other organic media
e.g.
- ● Acrylonitrile
- ● Carbon disulfide
- ● Dimethyl sulfoxide
- ● Epichlorohydrine
- ● Mercaptans
- ● Nitrobenzene
- ● Phenol
- ● Silicones
- ● Siloxanes
- ● Thionyl chloride

Technical mixtures
e.g.
- ● Heat transfer oils
- ● Hydraulic oils
- ● Motor oils
- ● Paint thinner
- ● Paraffin oil (kerosene)
- ● Petrol (gasoline)
- ● Transformer oil

Alkalis
e.g.
- ● Ammonia solution
- ● Caustic potash solution
- ● Caustic soda solution
- ● Potassium hydroxide up to 400°C
- ● Sodium hydroxide up to 400°C

Aqueous salt solutions
e.g.
- ● Borates
- ● Bromides
- ● Carbonates
- ● Chlorides
- ● Chromates, 20 % conc.
- ● Fluorides
- ● Iodides
- ● Nitrates
- ● Nitrites
- ● Phosphates
- ● Sulfates

Oxidizing molten salts
- ■ Potassium chlorate
- ■ Potassium nitrate
- ■ Sodium peroxide

Non-oxidizing molten salts
- ● Borate, soda, potash
- ● Calcium chloride
- ● Potassium hydrogen sulfate

Metal melts
e.g.
- ● Aluminum
- ● Copper
- ● Gold
- ■ Iron
- ● Lead
- ● Magnesium
- ● Mercury
- ● Potassium up to 350°C
- ● Silver
- ● Tin
- ● Wood's alloy
- ● Zinc

Acids
e.g.
- ■ Aqua regia
- ● Boric acid
- ● Bromic acid
- ● Chromosulfuric acid up to 20 %
- ● Hydrochloric acid
- ● Hydrofluoric acid
- ■ Nitrating acid
- ● Nitric acid up to 65 %
- ■ Nitric acid > 65 %
- ■ Oleum
- ● Perchloric acid up to 20 %
- ● Phosphoric acid
- ● Sulfuric acid up to 70 %
- ● Sulfuric acid 70-100 % up to 100°C
- ● Sulfurous acid

Gases/vapors
e.g.
- ● Air, at more than 400°C subject to prior consultation
- ● Ammonia
- ■ Bromine
- ● Carbon dioxide up to approx. 600°C
- ● Carbon monoxide
- ■ Chlorine dioxide
- ● Chlorine, dry
- ■ Chlorine, moist at > 30°C
- ▲ Fluorine
- ● Hydrogen bromide
- ● Hydrogen chloride
- ● Hydrogen fluoride
- ● Hydrogen sulfide
- ● Nitrogen
- ● Nitrogen dioxide up to approx. 600°C**)
- ● Nitrous oxide**)
- ▲ Oxygen up to approx. 350°C
- ● Phosgene
- ● Sulfur dioxide
- ● Sulfur hexafluoride
- ■ Sulfur trioxide

Other inorganic media
- ● Bleach liquor
- ● Hydrazine
- ● Sulfur

● resistant
■ not resistant
▲ reservedly resistant

*) without oxygen ingress
**) dry gases only
***) The resistance of reinforced SIGRAFLEX gaskets can be checked in our Technical Information "SIGRAFLEX Gaskets – Resistance to Chemical Media"

MARKET APPROACH AND CUSTOMER SERVICE

OUR EXPERTISE IS YOUR ADVANTAGE

Our Expertise

Analytical Lab
- R & D in sealing systems
- Comprehensive seal testing
- Continuous product improvement

Excellent Product Quality
- Selected raw materials
- Low leakage rates
- High blow-out resistance
- Superior oxidation resistance
- Fire safety

Worldwide Product Availability
- Available from stock in various dimensions
- For universal use over a wide range of applications

Service
- Technical support in sealing selection and installation
- Training on fluid sealing-related issues
- Worldwide sales offices
- Advice on seal design and calculation

Your Advantage

- Outstanding product reliability
- Long service life
- Skilled maintenance staff
- Less downtimes
- Saving of resources
- Reduced total costs of ownership

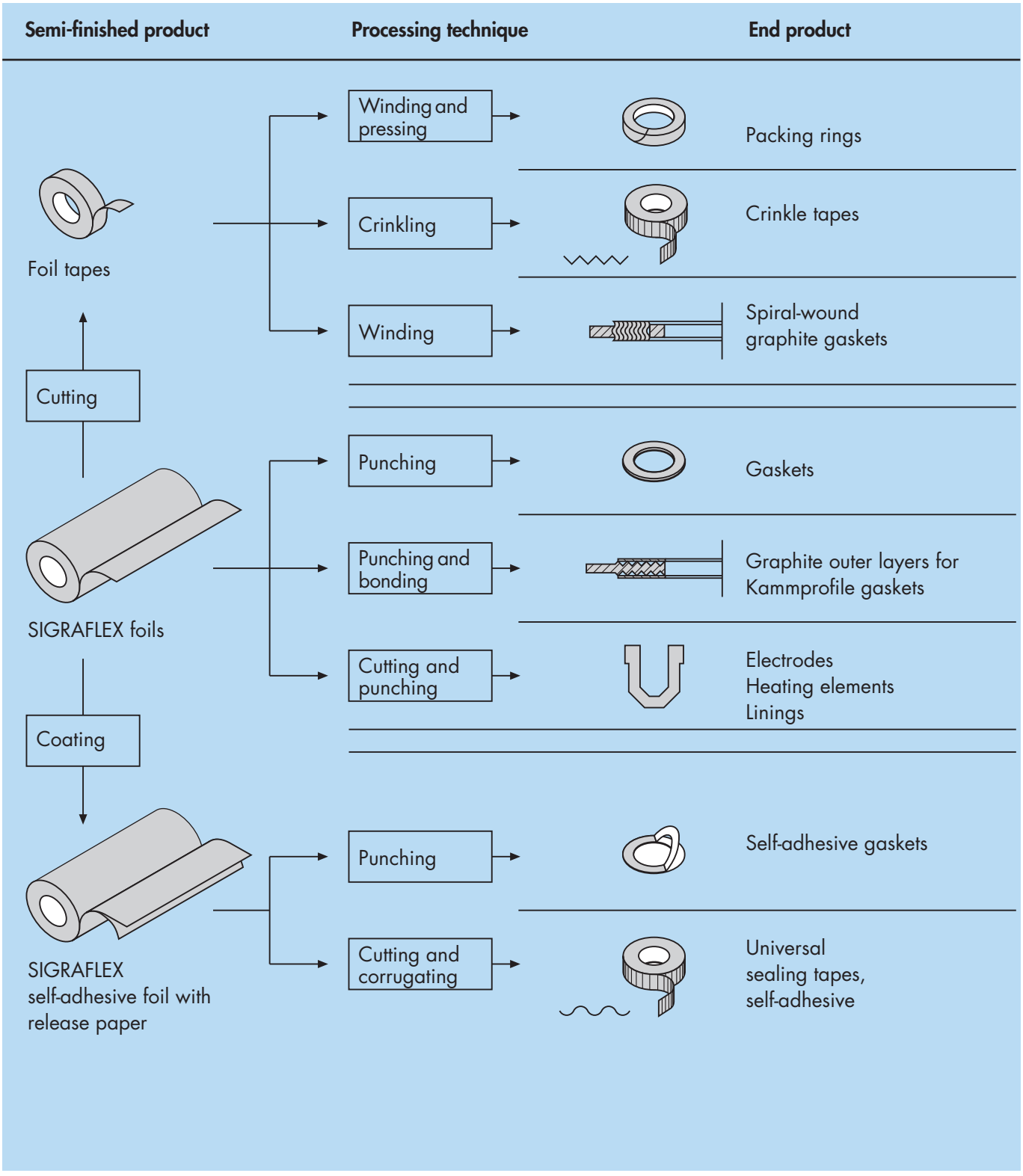
Enhances

- **Environmental Protection**
- **Safety and Plant Availability**
- **Cost Savings**

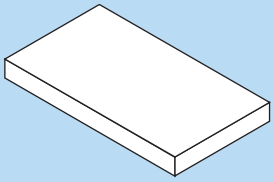
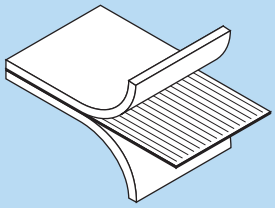
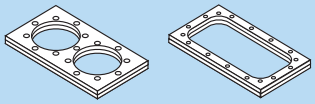
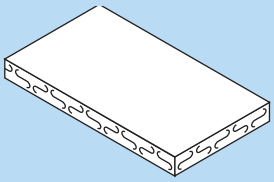
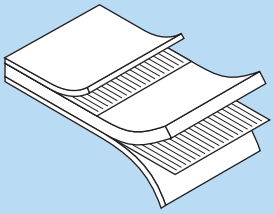
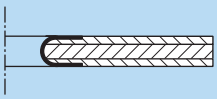
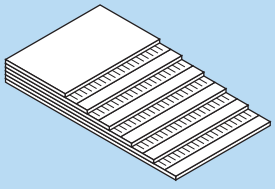
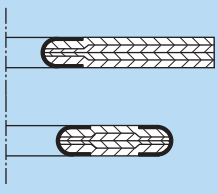
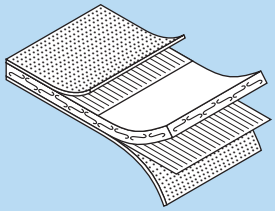
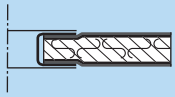
High Performance and Safety in Sealing Systems

PROCESSING OF SIGRAFLEX FOILS

Our semi-finished SIGRAFLEX products are processed in various branches of industry into a wide variety of seals and other components by the techniques summarized below. The soft material is easy to punch and cut with standard tools.



PROCESSING OF SIGRAFLEX SHEETS

	SIGRAFLEX product	Processing technique	End product
Unreinforced sheets	SIGRAFLEX BASIS + SIGRAFLEX STANDARD 	Punching Cutting Scarf cutting Bonding 	Simple gaskets Smooth stainless steel ring gaskets with graphite outer layers Corrugated stainless steel ring gaskets with graphite outer layers
Reinforced sheets	SIGRAFLEX ECONOMY 	Punching Cutting Scarf cutting Bonding 	Gaskets for pumps and fittings
	SIGRAFLEX UNIVERSAL SIGRAFLEX UNIVERSAL *PRO* 	Punching Cutting Scarf cutting Bonding 	Gaskets for pipework UNIVERSAL *PRO*: For applications subject to the German TA Luft (Clean Air Act)
	SIGRAFLEX SELECT 	Punching Cutting Typical gasket section 	Gaskets with s/s inner eyelets for raised-face flanges, in applications subject to the German TA Luft (Clean Air Act)
	SIGRAFLEX HOCHDRUCK SIGRAFLEX HOCHDRUCK *PRO* 	Punching Cutting Scarf cutting Bonding Typical gasket sections 	High-quality gaskets with metal eyelets for universal applications HOCHDRUCK *PRO*: For applications subject to the German TA Luft (Clean Air Act)
	SIGRAFLEX MF 	Punching Cutting 	Superior-quality gaskets with s/s inner eyelets for maximum sealability and safety

The flexible graphite is shown in white color. The metal foils are shown as hatched surfaces. The PTFE foils are shown as dotted surfaces

ADVICE ON APPLICATION FOR STUFFING BOX PACKINGS

Key words	Results of using SIGRAFLEX in practical situations
Maintenance	Low maintenance expenditure due to long service life and hence short downtimes.
Shaft wear	Low; SIGRAFLEX is soft and self-lubricating.
Friction coefficients	Between 0.08 and 0.25 against steel with sliding speeds of up to 30 m/sec and in the presence of small quantities of moisture.
Packing height	Low, owing to high density. Individual rings can be subsequently added to a packing if the gland cannot be tightened further.
Packing structure	Marked improvement in service behavior obtained with braided carbon fiber packing rings.
Leakage rate	Low, even with short packings and high pressure differentials.
Heat dissipation	Very good owing to high thermal conductivity up to 400 W/(K· m).
Fire safety test	Fittings with packings manufactured by our customers from SIGRAFLEX material have proved satisfactory in this test.

ADVICE ON APPLICATION FOR GASKETS

Key words	Results of using SIGRAFLEX in practical situations
Gasket pressure	Owing to their high compressibility, SIGRAFLEX gaskets are useful for sensitive and/or uneven flanges, e.g. those made of glass, enamel or graphite. The homogeneous distribution of the gasket pressures ensures an optimum sealing effect.
Maximum gasket pressure	High gasket pressures are permissible even at high temperatures. The selected SIGRAFLEX type should be suitable for the specified width-thickness ratio.
Bolt forces	As a rule, the bolt forces should be used to the full.
Service pressure	Very high service pressures can be accommodated reliably by using a properly selected SIGRAFLEX type (e.g. HOCHDRUCK).
Cold and warm flow	None detected up to maximum permissible gasket pressure; hence no need for retightening the bolts while plant or equipment is in use.
Service lives	Very high in comparison with conventional material (e.g. longer lives due to very good oxidation resistance).
Microsealing and macrosealing	SIGRAFLEX adapts very well to ultrafine or coarse surface irregularities. Hence, no special demands need be imposed on the flange surfaces.
Leaking flange joint	In the case of liquids, never retighten flange bolts – always replace the gasket.
Fire safety test	BS 6755-2 and API 607 certificates have been issued for a number of high-quality SIGRAFLEX materials.
Gaskets of large and complicated design	Can be assembled from segments.
Release agents	Never pretreat gaskets with oil or grease.
Wet or moisture	Moist gaskets must not be fitted (drying allowed).
Dismantling	SIGRAFLEX gaskets are easy to remove and involve no health risk.
Disposal	Uncontaminated material can be disposed of without any problems.

Table 6

High-quality SIGRAFLEX gasket systems and fields of application

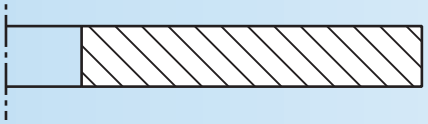
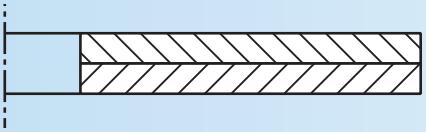
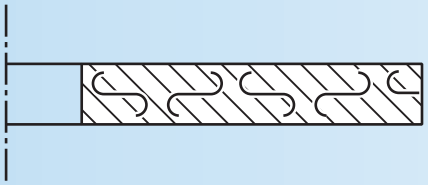
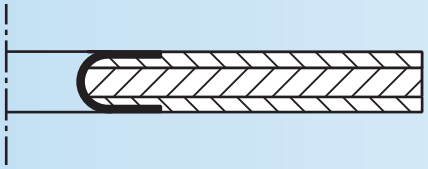
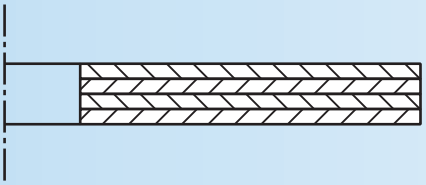
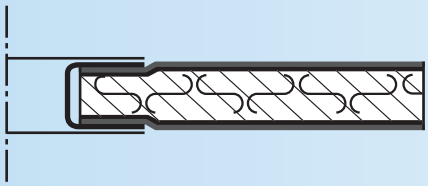
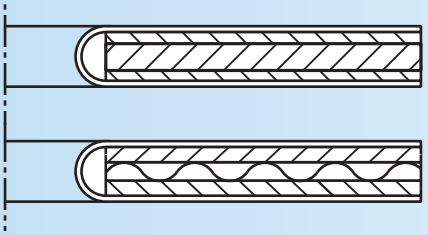
SIGRAFLEX type	Cross-section	Characteristics	Field of application
STANDARD		Unreinforced, impregnated	Glass/enamelled flanges, complicated designs, highly corrosive media (e.g. HCl)
ECONOMY		Reinforced with bonded stainless steel foil	Gas technology; pumps and fittings; offshore
UNIVERSAL UNIVERSAL *PRO*		Reinforced with perforated s/s sheet, impregnated	For pipework and vessels in the chemical and petrochemical industries and in power stations; UNIVERSAL *PRO*: For applications subject to the German TA Luft (Clean Air Act)
SELECT		High-integrity s/s foil reinforcement, impregnated	For applications subject to the German TA Luft (Clean Air Act); raised-face flanges; pipework in the chemical and petrochemical industries
HOCHDRUCK HOCHDRUCK *PRO*		High-integrity multilayer laminate, impregnated, reinforced with s/s foil	Universal problem-solving gasket material for the process industries to meet demanding requirements for sealability and safety (e.g. tongue-and-groove flanges); ease of processing and assembly. HOCHDRUCK *PRO*: For applications subject to the German TA Luft (Clean Air Act)
MF		High-integrity laminate made of graphite, stainless steel and PTFE	Maximum requirements for sealability, safety, chemical resistance and process hygiene; sealed joints in the chemical, petrochemical, pharmaceutical and food industries
EMAIL		PTFE-envelope gasket with SIGRAFLEX EMAIL core	For enamelled flanges, exacting demands for sealability and process hygiene in the pharmaceutical industry, aggressive media

Table 7 **Recommended SIGRAFLEX products for various applications**

Industries	Components	Products						
		SIGRAFLEX STANDARD	SIGRAFLEX ECONOMY	SIGRAFLEX UNIVERSAL SIGRAFLEX UNIVERSAL *PRO*	SIGRAFLEX SELECT	SIGRAFLEX HOCHDRUCK SIGRAFLEX HOCHDRUCK *PRO*	SIGRAFLEX MF	SIGRAFLEX EMAIL in PTFE envelopes
TA Luft				■	■	■	■	■
Automotive industry	Exhaust systems			■		□		
	Cylinder-head gaskets			■		□		
Chemical industry	Standard flanges		□	■	■	■	■	
	Tongue-and-groove flanges					■		
	Vessel/equipment flanges			□		■		
	Gaskets up to 1500 mm diam.			■		■		□
	Glass/plastic/enamel surfaces	■						■
	Highly corrosive media*)	■						■
	High gasket pressures			□	□	■	□	
	Mechanical shear movements			□	■	■	■	□
Gas technology			□	■	■	■	■	
Power station technology	Fittings			■		■		
	Vessels/equipment			□		■	□	
	Pipework			□	□	■	□	
	Inspection glasses			□		■		
	Waste gas purification		□	■	■	■		
Engine building			■	□		■		
Food industry					□		■	■
Water supply		□		□	■	■	■	

■ recommended
□ suitable**)

*) to which the metal reinforcements (ASTM material no. 316 (L)) are not resistant

**) each individual case needs to be considered separately

COMMONLY USED CONVERSION FACTORS

Units of Length

	mm	cm	m	inch	foot	yard
mm	1	0.1	$1 \cdot 10^{-3}$	0.0394	$3.281 \cdot 10^{-3}$	$1.094 \cdot 10^{-3}$
cm	10	1	0.01	0.3937	0.03281	$1.094 \cdot 10^{-2}$
m	1000	100	1	39.37	3.281	1.094
inch	25.4	2.54	0.0254	1	0.0833	$2778 \cdot 10^{-2}$
foot	304.8	30.48	0.3048	12	1	0.33
yard	914.4	91.44	0.914	36	3	1

Units of Area

	mm^2	cm^2	m^2	$inch^2$	$foot^2$	$yard^2$
mm^2	1	10^{-2}	10^{-6}	$1.55 \cdot 10^{-3}$	$1.076 \cdot 10^{-5}$	$1.196 \cdot 10^{-6}$
cm^2	10^2	1	10^{-4}	0.155	$1.076 \cdot 10^{-3}$	$1.196 \cdot 10^{-4}$
m^2	10^6	10^4	1	1550	10.764	1.196
$inch^2$	645.2	6.452	$6.452 \cdot 10^{-4}$	1	$6.94 \cdot 10^{-3}$	$7.716 \cdot 10^{-4}$
$foot^2$	$9.29 \cdot 10^{-4}$	929	$9.29 \cdot 10^{-2}$	144	1	0.111
$yard^2$	$8.36 \cdot 10^5$	$8.36 \cdot 10^3$	0.836	1296	9.009	1

Units of Volume

	cm^3	liter	m^3	$inch^3$	$foot^3$	gallon
cm^3	1	10^{-3}	10^{-6}	0.06102	$3.53 \cdot 10^{-5}$	$2.64 \cdot 10^{-4}$
liter	1000	1	0.001	61.02	0.03532	0.2642
m^3	10^5	1000	1	$6.1 \cdot 10^4$	35.32	264.2
$inch^3$	16.39	0.01639	$1.64 \cdot 10^{-5}$	1	$5.79 \cdot 10^{-4}$	$4.33 \cdot 10^{-3}$
$foot^3$	$2.83 \cdot 10^4$	28.32	0.02832	1728	1	7.481
gallon	3785	3.785	$3.785 \cdot 10^{-3}$	231	0.1337	1

Weight Units

1kg = 2.2046 lb = 35.274 oz
1lb = 16 oz = 0.45359 kg

COMMONLY USED CONVERSION FACTORS

Units of Density

1 kg/l	= 1g/cm³	= 62.42 lb/ft³	= 9271.1 lb/in³	
1 lb/ft³	= 5.787·10⁻⁴ lb/in³	= 0.01602 g/cm³		
1 lb/in³	= 1728 lb/ft³	= 107.86 g/cm³		

Units of Force

1 N	= 0.2248 lbf
1 lbf	= 4.448 N

Units of Pressure and Stress

1 N/m²	= 1 Pa	= 10⁻⁶ N/mm²	= 1.45037·10⁻⁴ lbf/in² (psi)
1 MPa	= 1 N/mm²	= 10.2 bar	= 145.037 lbf/in² (psi)
1 bar	= 760 mm Hg	= 29.92 inch Hg	= 14.5 psi
1 psi	= 144 lbf/ft²	= 6.895 kPa	= 6.895·10⁻³ N/mm²
	= 6.895·10³ N/m²	= 6.895·10⁻² bar	
1 mm Hg	= 0.03937 inch Hg	= 0.01934 psi	= 0.001315 bar
1 inch Hg	= 0.4912 psi	= 1.133 ft water	

Units of Energy, Moment

1 Ws	= Nm	= 1 Joule	= 0.948 BTU	= 0.738 lbf·ft
1 lbf·ft	= 1.356 Nm	= 1.3558 Joule	= 1.285 BTU	

Units of Flow Rate

	l/s	gal/min	ft³/s	ft³/min
l/s	1	15.85	0.03532	2.119
gal/min	0.0631	1	0.00223	0.1337
ft³/s	28.32	448.8	1	60
ft³/min	0.4719	7.481	0.01667	1

COMMONLY USED CONVERSION FACTORS

Units of Temperature

$t_C = 5/9(t_F - 32)$ °C $t_F = (1.8 \cdot t_C) + 32$ °F

°C	°F	°C	°F	°C	°F	°C	°F
-100	-148	0	32	100	212	200	392
- 90	-130	10	50	110	230	250	482
- 80	-112	20	68	120	248	300	572
- 70	- 94	30	86	130	266	350	662
- 60	- 76	40	104	140	284	400	752
- 50	- 58	50	122	150	302	450	842
- 40	- 40	60	140	160	320	500	932
- 30	- 22	70	158	170	338	550	1022
- 20	- 4	80	176	180	356	600	1112
- 10	14	9	194	190	374	1000	1832

Units of Thermal Conductivity

1 BTU/(hr °F) · ft²/ft = 1.731 W/(K· m) 1 W/(K· m) = 0.578 BTU/(hr °F) · ft²/ft

Unit of Resistivity

1 Ohm in = 25.4 · 10^3 Ohm µm 1 Ohm µm = 39.4·10^{-6} Ohm in

Units of Gas Permeability

Gas permeability (DIN 3535-4): $\frac{V}{t}$ in $\frac{cm^3}{min}$

Gas permeability (DIN 28090-1): $\lambda = \frac{V}{t} \cdot \frac{\rho}{\pi \cdot d_D}$ in $\frac{mg}{s \cdot m}$

Conversion DIN 3535 into DIN 28090: $1 = \frac{cm^3}{min} \approx 0.094 \frac{mg}{s \cdot m}$

ρ	in mg/cm³	Density of test gas under normal conditions
d_D	in m	Mean efficient gasket diameter (0.07 m)

Conversion of leakage rates for nitrogen:

1 mbar·l/s = 1.19 mg/s = 0.952 cm³/s = 57.12 cm³/min

DEFINITIONS OF GASKET FACTORS

Definitions of gasket factors used in old and new regulations

DIN EN 13555	DIN 28090	Explanation
$Q_{MIN(L)}$	$\sigma_{VU/L}$	Minimum level of surface pressure required for leakage rate class **L** on assembly [MPa]
	σ_{BU}	Minimum gasket pressure under service conditions, where σ_{BU} is the product of internal pressure p and gasket factor m for test and service conditions [$\sigma_{BU} = p \cdot m$]
$Q_{S\ MIN(L)}$	$\sigma_{BU/L}$	Minimum level of surface pressure rate class **L** after off-loading [MPa]
$Q_{S\ MAX}$	σ_{BO}	Maximum surface pressure that can be safely imposed upon the gasket at service temperature without damage [MPa]
	σ_{VO}	Maximum permissible gasket pressure at RT [MPa]
E_G		Secant unloading modulus of the gasket [MPa]
P_{QR}		Ratio of gasket surface pressure before and after relaxation
L_N	L_N	Leakage rate class – subscript N indicates the max. specific leakage rate for that leakage rate class [mg s^{-1} m^{-1}]

The definitions of the older gasket factors (DIN V 2505 of 1964, AD Merkblatt B7 of 1977) are as follows:

k_0	in mm	Factor for gasket assembly pressure
k_1	in mm	Factor for gasket pressure under service conditions
k_2	in mm	Factor for max. stress-bearing capacity under service conditions
K_D	in N/mm²	Max. gasket stress-bearing capacity under assembly conditions
$K_{D\vartheta}$	in N/mm²	Creep strength under compressive stress at service temperature
b_D	in mm	Gasket width

The following conversion formulas are used:

$$\sigma_{VU} = Q_{min} = \frac{k_0 \cdot K_D}{b_D} \qquad m = k_1 / b_D$$

$$\sigma_{VO} = Q_{max} = V\,\frac{k_0 \cdot K_D}{b_D} \qquad \sigma_{BO} = Q_{max} = V\,\frac{k_2 \cdot K_{D\vartheta}}{b_{D\vartheta}}$$

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