EVONIK INDUSTRIES

Reliable thermoplastic polymers for oil & gas applications

VESTAMID® NRG
VESTAKEEP®

Evonik. Power to create.

The bundle of energy

High performance solutions
for the energy market

Contents

VESTAMID® NRG

The highest level of efficiency and performance

About Evonik

German-based Evonik Industries is one of the world leaders in specialty chemicals. The Resource Efficiency segment supplies high performance materials for environmentally friendly as well as energy-efficient systems. Its High Performance Polymers business line has been producing high-performance plastics for over 50 years which are suitable for a virtually unlimited range of uses, including a particularly large number of applications in the energy sector. High performance polymers are used in photovoltaic modules, wind power facilities, gas separation modules, and in the oil and gas industry. Depending on the application, these polymers provide protection against corrosion or chemicals, increase the safety of energy transport, or enhance the efficiency of energy generation.

More energy with VESTAMID® NRG

The polyamide 12 VESTAMID® NRG is specifically developed for efficient gas and oil pipelines. It has been the material of choice for thousends of kilometers of unbonded flexible pipes since 2006.
VESTAMID® NRG has extraordinary resistance to mechanical stresses, stress fracturing, and chemicals such as crude oil. Thanks to these properties, it can be used to protect the exterior and interior of onshore and offshore oil and gas pipelines. It bundles energy by making the transport and extraction of fossil energy sources more efficient.

Further applications of polyamide 12

The applications of polyamide 12 range from sophisticated fluid line systems such as fuel lines, through core insulation in the cable industry and catheters in medical technology, to precision injection-molded parts like impellers and control-valve housings in machine and equipment manufacture.

General properties of polyamide 12

- Extraordinarily high impact resistance and Charpy notched impact strength, even well below freezing point.
- Excellent resistance to fatigue caused by frequent load change
- Good to excellent resistance to greases, oils, fuels, hydraulic fluids, and many solvents as well as to salt solutions and other chemicals
- Excellent resistance to stress cracking, even for metal parts encapsulated by injection molding or embedded into the plastic
- Excellent slow crack growth behavior
- Excellent abrasion resistance
- Low dry sliding friction coefficient
- Noise and vibration damping properties
- Minimal water absorption: Molded parts show almost no dimensional changes with variation in atmospheric humidity.
- Easy processability

VESTAKEEP® PEEK

A multitalent among the high performace polymers

Taking the heat and pressure with VESTAKEEP® PEEK*

VESTAKEEP® PEEK (polyether ether ketone) compounds are particularly suitable for applications in which extremely high mechanical, thermal, and chemical requirements must be met. Thanks to these properties, they can be used to protect onshore and offshore oil and gas pipelines against corrosion and wear even under high temperature and high pressure conditions. VESTAKEEP® PEEK has been the material of choice for anti-wear tapes in demanding unbonded flexible pipe designs. Other typical applications in O&G are sealing rings, compressor parts and valve parts.

VESTAKEEP® PEEK bundles energy by making the transport and extraction of fossil energy sources more efficient. This is tested and confirmed in accordance to NORSOK M710.

* PEEK is the official abbreviation for polyether ether ketone according to ISO 1043. In this brochure it will be used only in this context.

Further applications of PEEK

The applications of PEEK range from automotive parts requiring high frictional forces and high temperatures to composite components in aerospace construction, to wafer carrier applications and high demanding cable sheathing in the electrical industry.

General properties of PEEK

- Very high thermal stability and high long-term thermal stability
- Good balance of extreme rigidity and hardness with good flexural fatigue strength
- Low water absorption and thus high dimensional stability and stable electrical and mechanical properties
- Self-extinguishing and halogen-free with low toxicity and optical smoke density
- Excellent sliding friction behavior, minimal abrasion
- Outstanding chemical and hydrolysis resistance
- Low tendency to form stress cracks and low creep at high load
- Low compression set for good sealing properties

Flexible pipes

VESTAMID® NRG applied in unbonded flexible pipes

VESTAMID® NRG – The leading-edge in flexible pipe technology

VESTAMID® NRG – polyamide 12 (PA12)
Polyamide 12 is a high performance thermoplastic polymer with increased performance characteristics that translates into safe operations over the life of the installed flexible pipe. It has a considerable record of safe and proven experience in many demanding applications, including fuel lines in passenger cars, air brake tubing in trucks, and gas pipe applications.

VESTAMID® NRG 1001 is a high molecular weight grade of PA12 material developed by Evonik.
Its superior performance characteristics make it an ideal choice for demanding flexible pipe applications contributing to efficient and safe operations.

Flexible pipes with a VESTAMID® NRG 1001 pressure layer offer increased operation temperature. At same design temperatures this advantage leads to a significant life time extension and adds value to the buttom line.

Besides extending the lifetime limits of flexible pipes, VESTAMID® NRG 1001 offers many additional benefits, and in most instances superior performance, as compared to conventional polyamide.

- Superior ductility
- Excellent fracture mechanical performance even under arctic conditions
- High creep and compression creep resistance
- Good methanol resistance
- Excellent heat ageing resistance
- Easy to process

These characteristics make VESTAMID® NRG an ideal choice when selecting appropriate thermoplastic materials in flexible pipe application.

VESTAMID® NRG 1001 material complies with API 17 J specifications.
More than 1000 km unbonded flexible pipe have been manufactured using VESTAMID® NRG as barrier or jacket layer serving several leading oil companies in offshore operations.

1 – Mechanical properties of VESTAMID® NRG 1001 at 23°C

Property	Test method	VESTAMID® NRG 1001	Unit
Yield stress (23°C)	ASTM D638	27.0	MPa
Yield strain (23°C)	ASTM D638	32.5	%
Stress at break (23°C)	ASTM D638	51.4	MPa
Strain at break (23°C)	ASTM D638	>200	%
Tensile modulus (23°C)	ASTM D638	450	MPa
Poisson ratio (23°C)	ASTM D638	0.47	–
Shore hardness A (1s)	ASTM D2240	98	–
Shore hardness A (15s)	ASTM D2240	98	–
Shore hardness D (1s)	ASTM D2240	62	–
Shore hardness D (15s)	ASTM D2240	60	–
Compressive modulus (23°C)	ISO 604 / ASTM D695	490	MPa
Compressive modulus (60°C)	ISO 604 / ASTM D695	300	MPa
IZOD (23°C) impact strength	ASTM D256	1110	J/m
Density	ASTM D792	1.02	g/cm^3

2 – Thermal properties of VESTAMID® NRG 1001

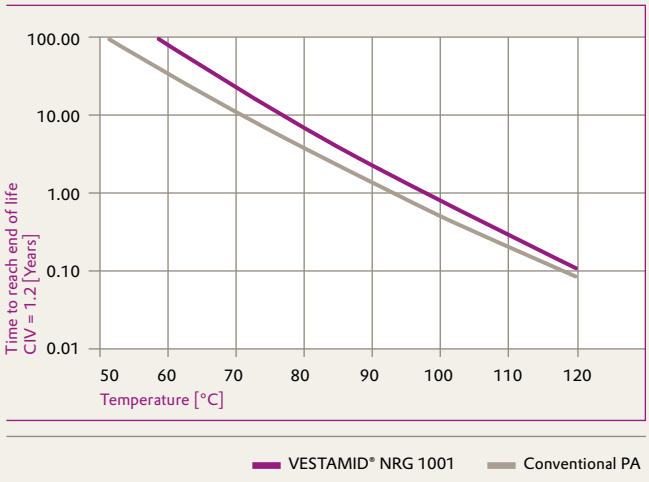
Property	Test method	VESTAMID® NRG 1001	Unit
Thermal conductivity coefficient	ASTM C177	0.25	W/(m·K)
Thermal expansion coefficient (23 – 55°C)	ASTM E831	160	µm/(m·K)
Softening point Vicat A (10N)	ASTM D1525	163	°C
Softening point Vicat B (50N)	ASTM D1525	129	°C
Heat distortion temperature (HDT A – 1.8 MPa)	ASTM D648	45	°C
Heat distortion temperature (HDT B – 0.45 MPa)	ASTM D648	139	°C
Heat capacity DSC (23°C)	ASTM E1269	2.15	J/(g·K)
Melt temperature DSC	ASTM D3418	171	°C
Heat of fusion DSC	ASTM D3418	63	J/g
Heat of fusion (100% crystalline)	theoretical	210	J/g

VESTAMID® NRG – Superior performance characteristics for the intended application

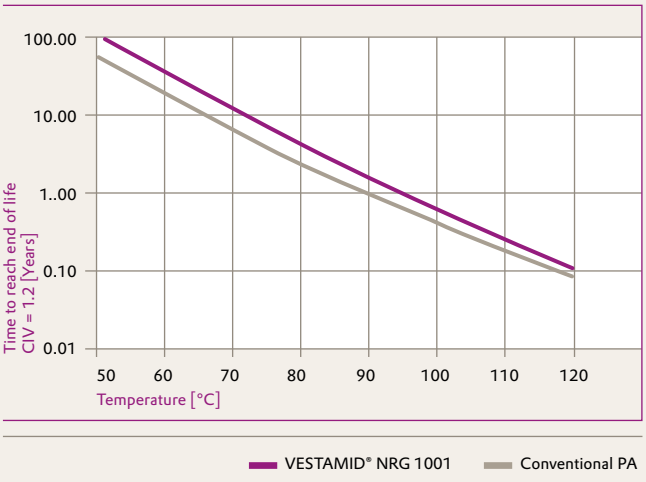
A key to building world class flexible pipes is using materials with superior performance characteristics and a proven track record of safety for the intended application.

VESTAMID® NRG exhibits the following key performance characteristics and benefits which makes it an ideal material for flexible pipes.

3 – Arrhenius lifetime curve considering no CO_2 partial pressure



4 – Arrhenius lifetime curve considering 10 bar CO_2 partial pressure

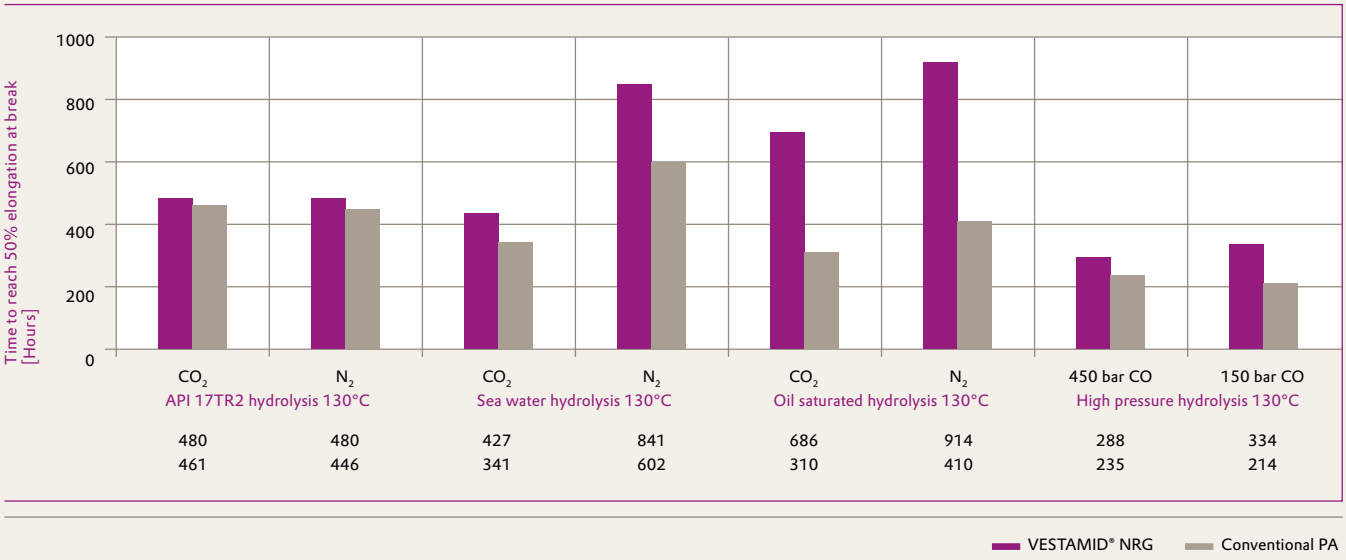


Excellent ageing performance in water (hydroysis)

Extensive research data and actual field performance validate the superior ageing performance of VESTAMID® NRG 1001. Ageing experiments in water in compliance with API 17 TR2 have been performed by Shell Global Solutions in the Netherlands. Chemical ageing of polyamides involves hydrolysis and oxidation. Because transported media in oil and gas applications are considered oxygen free, hydrolysis is the primary contributor to the chemical ageing process. VESTAMID® NRG 1001 and a conventional polyamide used in flexible pipes were simultaneously exposed to exactly the same ageing conditions to generate a comprehensive set of comparable data. These data were translated into Arrhenius lifetime curves and corresponding lifetime estimates in compliance with API 17 TR 2.

Based on this estimation the flexible pipe design engineer calculates the expected lifetime of the polyamide layers depending on the design temperature. Due to its superior hydrolysis resistance VESTAMID® NRG 1001 is able to withstand higher continuous operation temperature considering a design lifetime of 20 years compared to the conventional polyamide. Extensive additional research work confirmed the superior ageing performance also under additional testing conditions, e.g., considering $scCO_2$, sea water, and crude oil saturation.
For dynamic applications such as riser the end of lifetime is considered by reaching a CIV of 1.2 dl/g.

5 – Ageing under field conditions



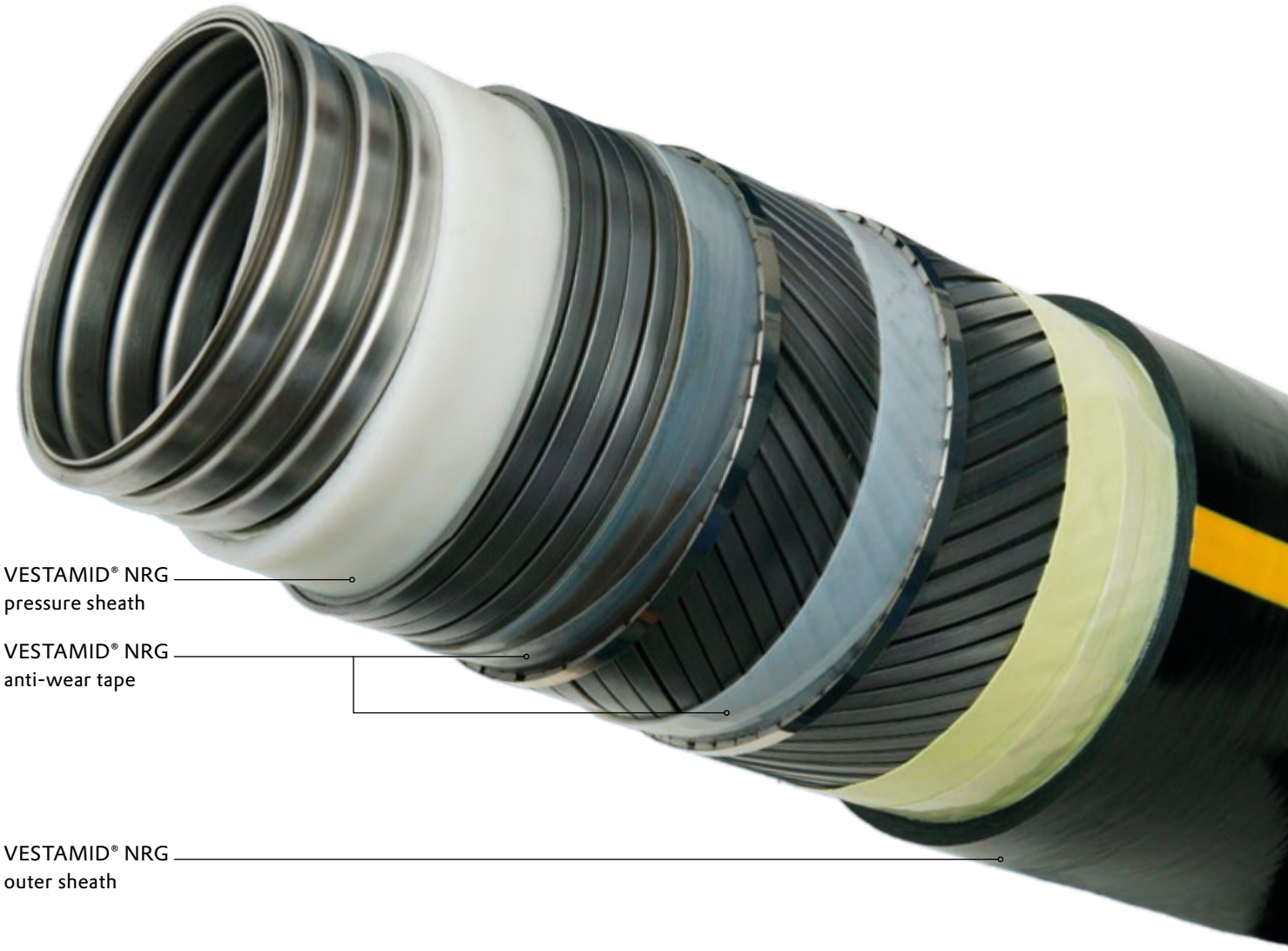
Excellent ductility and fracture mechanical performances

The proven record of polyamide in flexible pipe applications highlights its excellent performance characteristics under operating conditions. Nevertheless new challenging frontiers result in increasingly demanding requirements on the exploration and production equipment. Extreme installation and operating temperature conditions must be considered in new arctic frontier flexible pipe applications.
With VESTAMID® NRG 1001 the operator can specify the most ductile and tough polyamide material available for flexible pipes.
Extensive fracture mechanics studies show that VESTAMID® NRG 1001 remains ductile even at -50 °C and until the end of its considered lifetime. This excellent low temperature ductility and fracture toughness contributes to safe installation procedures even under arctic conditions.

Proven track record

VESTAMID® NRG 1001 is used for oil and gas production all over the world. The applications vary from risers to flowlines and jumpers over the range of pipe size, operating pressure and installation environments. The transported fluids of the product pipelines vary from oil, oil/water to oil/water/gas multiphase fluids.
As a consequence, VESTAMID® NRG is broadly accepted as a material of choice in the flexible pipe industry and leading oil companies such as Petrobras, ExxonMobil, Chevron and Statoil are typical end users.

In general, VESTAMID® NRG 1001 offers a safe and reliable material to both the designer and operator of flexible pipes.


VESTAMID® NRG
pressure sheath
VESTAMID® NRG
anti-wear tape
VESTAMID® NRG
outer sheath

Liner

VESTAMID® NRG – The alternative to CRA and clad pipes for oil and gas production pipelines

In addition to the use of VESTAMID® NRG in more than thousend kilometers of flexible pipes the industry has recognized the positive track record of water injection pipelines lined with thermoplastic liners. This technology using PE as liner material is state of the art and looks back to several decades of successful service. Its significant advantages in capex and opex as well as its proven reliability have convinced operators of production pipeline assets globally.
With VESTAMID® NRG as liner material this technology is now ready to be transferred to production pipelines as an alternative to corrosion inhibitor, CRA (**C**orrosion **R**esistant **A**lloys) and clad solutions. This evolution of technology is only a small step opening tremendous cost saving potential plus significant advantages in the supply chain.
VESTAMID® NRG 3000 series is a high molecular weight non-plasticized grade of PA12 material developed by Evonik. Its tailored performance characteristics make it an ideal choice for demanding liner application contributing to efficient and safe operations.
Due to its mechanical strength after saturation in crude (figure 8), and its low swelling in hydrocarbons (figure 9) even at elevated temperatures VESTAMID® NRG liners do allow the design of collapse resistant liner, e.g., in stabilized crude applications.
VESTAMID® NRG PA12 features good barrier properties for vapors and gases. The BTX permeation is a factor 200 lower than through HDPE, and also the permeation of methane gas is much smaller compared to HDPE even at elevated temperatures. Nevertheless, if it comes to high gas loads a venting technology should be considered to purge annular gas accumulated by permeation. In addition the compression fit design along with additional considerations of the overall specification of the pipeline contributes to a safe and reliable operation even under such demanding conditions.

Key advantages of a VESTAMID® NRG liner are:

- Significant savings compared to corrosion inhibitor program
- Significant cost savings and better availability compared to CRA and clad design
- No corrosion by H_2S and CO_2
- High local content possible
- No corrosion inhibition
- Spoolable without risk of liner buckling

6 - Mechanical properties of VESTAMID® NRG 3000 series at 23°C

Property	Test method	VESTAMID® NRG 3000 series	Unit
Yield stress (23°C)	ASTM D638	38	MPa
Yield strain (23°C)	ASTM D638	5.4	%
Stress at break (23°C)	ASTM D638	45	MPa
Strain at break (23°C)	ASTM D638	170	%
Tensile modulus (23°C)	ASTM D638	1320	MPa
Poisson ratio (23°C)	ASTM D638	0.43	–
Shore hardness A (1s)	ASTM D2240	98	–
Shore hardness A (15s)	ASTM D2240	99	–
Shore hardness D (1s)	ASTM D2240	75	–
Shore hardness D (15s)	ASTM D2240	72	–
Compressive modulus (23°C)	ISO 604 / ASTM D695	1250	MPa
Compressive modulus (60°C)	ISO 604 / ASTM D695	384	MPa
IZOD (23°C) impact strength	ASTM D256	404	J/m
Density	ASTM D792	1.015	g/cm^3

7 – Thermal properties of VESTAMID® NRG 3000 series

Property	Test method	VESATMID® NRG 3000 series	Unit
Thermal conductivity coefficient	ASTM C177	0.24	W/(m·K)
Thermal expansion coefficient (23 – 55°C)	ASTM E831	144	µm/(m·K)
Softening point Vicat A (10N)	ASTM D1525	170	°C
Softening point Vicat B (50N)	ASTM D1525	150	°C
Heat distortion temperature (HDT A – 0.45 MPa)	ASTM D648	45	°C
Heat distortion temperature (HDT B – 1.8 MPa)	ASTM D648	145	°C
Heat capacity DSC (23°C)	ASTM E1269	2.02	J/(g·K)
Melt temperature DSC	ASTM D3418	177	°C
Heat of fusion DSC	ASTM D3418	65	J/g
Heat of fusion (100% crystalline)	theoretical	210	J/g

VESTAMID® NRG – Broadening the application window of Reinforced Thermoplastic Pipes (RTP´s)

With VESTAMID® NRG as liner material the application window of RTP´s can be extended. Common RTP designs consider PE as liner material. This leads to limitations in terms of operation temperature especially in light oil applications. In gas operations the permeability of gas can limit the maximum possible operation pressure of PE based RTP designs. With VESTAMID® NRG as a liner material this limitation can be overcome.
A unique characteristic of VESTAMID® NRG is its excellent barrier properties against benzene, toluene and xylene often known as BTX. These hydrocarbons are components of gas condensates and could harm the environment. VESTAMID® NRG liners can reduce the permeation of these components by a factor of up to 200 compared to PE based RTP systems. Further information can be found in figure 10.

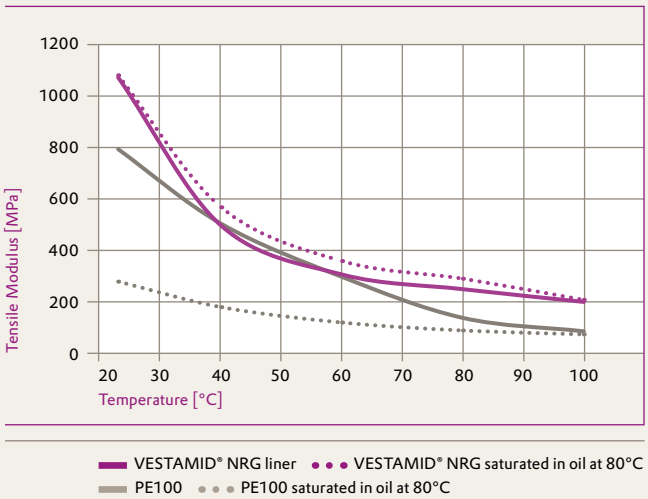
VESTAKEEP® PEEK – Enabling downhole liner application well above 150 °C operation conditions

High temperature thermoplastic liners are getting more and more in focus especially in downhole casings. With increasing requirements driven by high temperatures and high pressures operating conditions under harsh chemicals VESTAKEEP® PEEK polymer with its high temperature capabilities combined with its excellent impact resistance, strength and corrosion resistance offers a cost effective solution to replace expensive metallic corrosion resistant alloys (CRA).

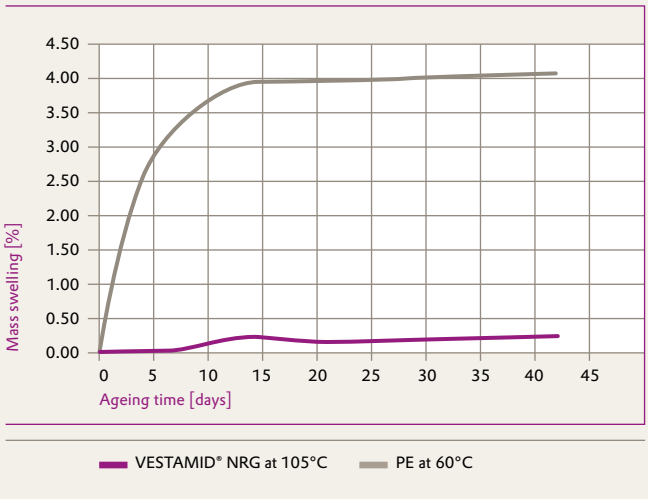
VESTAKEEP® PEEK polymer differentiates from other PEEK materials by:

- Higher impact resistance and ductility
- 50 % higher tensile modulus at 150 °C

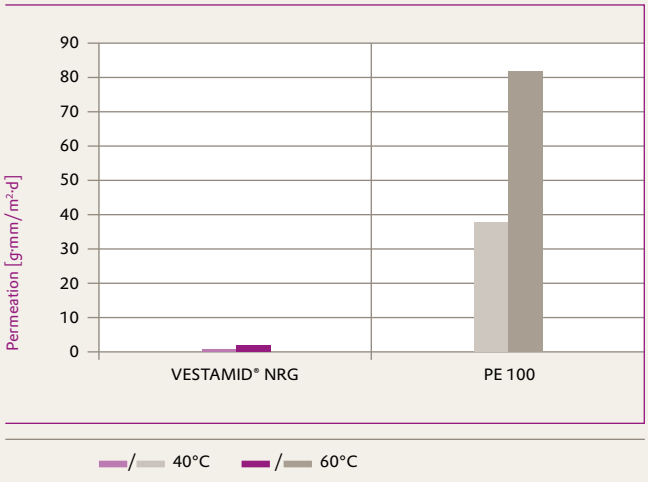
8 – High tensile modulus of VESTAMID® NRG 3000 series allows high collapse resistance even after saturation in oil



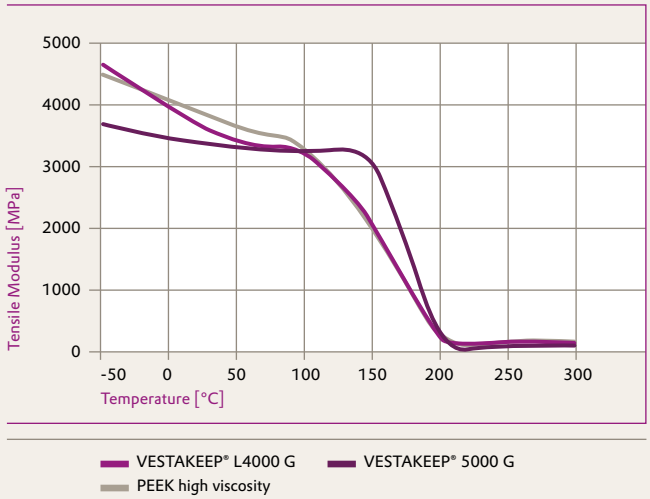
9 – Significant reduced mass swelling of VESTAMID® NRG 3000 series allows safe operations and avoids buckling



10 – Comparison of the BTX permeation



11 – Tensile modulus of VESTAKEEP® 5000 G depending on temperature



Thermoplastic composites
Pipes and risers

VESTAMID® NRG –
Reliability in new technologies

Thermoplastic Composite Pipes (TCP) and Thermoplastic Composite Risers (TCR) for the oil & gas offshore industry are getting more and more awareness. Today these types of pipes are used in relatively short term applications while developments on long term applications are progressing.

VESTAMID® NRG and VESTAKEEP® are materials with strong track record in subsea applications and are now available for multiple functions in TCP and TCR designs:

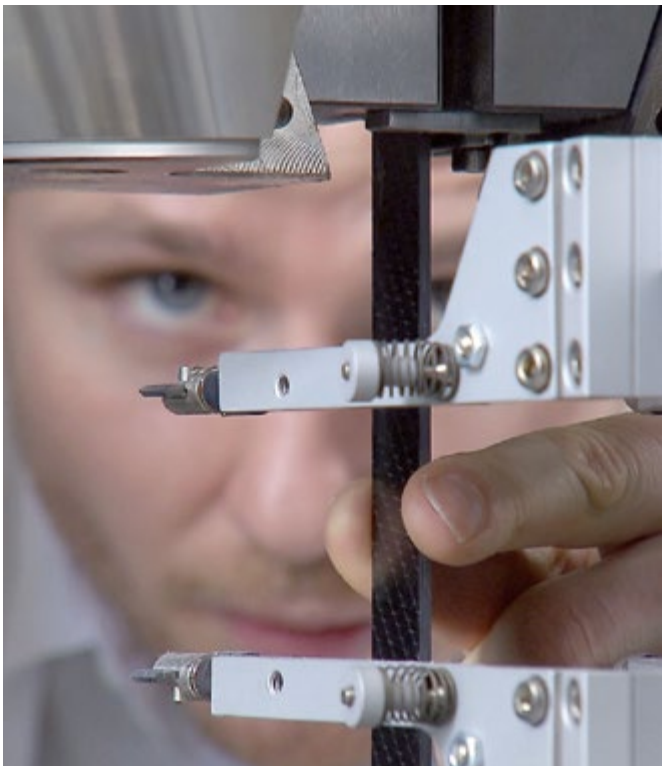
- as liner material suitable for multi phase operations
- as matrix material of the reinforcement layer
- as jacket material protecting the reinforcement layer against the environment

With VESTAMID® NRG 1003 Evonik has developed a tailored PA12 allowing the production of high quality unidirectional fiber tapes used for the reinforcement layer. The focus of this development was an optimized fiber matrix bonding and resistance to hydrolysis. Details on the material properties can be found in table 14.

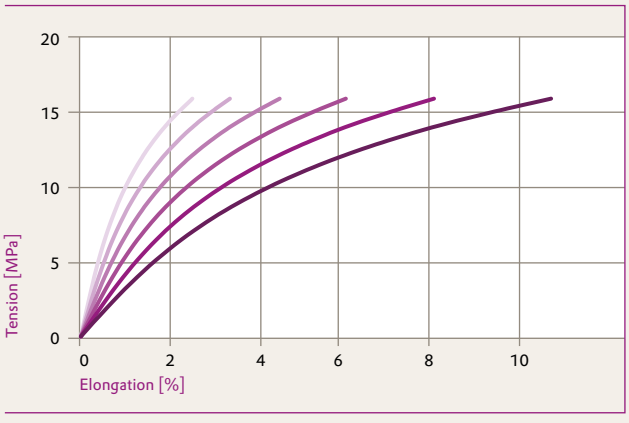
As described on page 14, PA12 grades of the VESTAMID® NRG 3000 series can be used as liner material. Its creep behavior is shown in graph 12.

Thermoplastic unidirectional tapes for TCP and TCR

Unidirectional tapes consist of endless fibers orientated in one direction embedded into a thermoplastic polymer matrix. Reinforcing properties of fibers can fully be exploited. These thin tapes (from 0.15–0.3 mm) are mainly processed in different tape laying or tape winding processes. In the oil and gas market, tapes are used to form continuous pipes and pipe sections.
To supply thermoplastic unidirectional tapes at high quality and reduced costs, Evonik has developed a new cost-efficient production process suitable for our high performance polymers. With this process, a tape based on polyamide 12 and glass fibers has been developed for oil and gas applications. VESTAMID® and VESTAKEEP® UD Tapes are based on PA12 and PEEK and can be combined with different fiber reinforcement, for example glass fibers and carbon fibers. Table 13 is showing example data for a PA12-SGF UD tape.



12 – Creep behavior of VESTAMID® NRG



0.1 h 1.0 h 10.0 h
100.0 h 1000.0 h 10000.0 h

Isochronous stress-strain curves according to ISO 899-1, creep rupture test at 23°C / 50% r.h.

13 – High quality UD tapes for thermoplastic composite pipes (example: PA12-SGF)

Property	Unit	UD tape
Thickness	[mm]	0.25
Fiber volume content	[%]	50
Mass per unit area	[g/m²]	275
Tensile modulus[1]	[MPa]	44,700
Tensile strength[1]	[MPa]	1,420
Strain at break[1]	[%]	3.2

[1] all material properties measured on tape samples acc. to DIN65469

Components for oil & gas applications

Three kinds of materials are available for the demanding field of oil and gas components:

- polyether ether ketone VESTAKEEP® PEEK
- polyamide 12 VESTAMID® NRG
- polyimide P84®.

PEEK performance under HPHT conditions

In response to industry demand for higher performing polyetheretherketone (PEEK) materials, Evonik offers VESTAKEEP® 5000 series PEEK compounds. These compounds are based on our speciality high molecular weight polymer that offer excellent combination of properties:

- Superior toughness, ductility and fatigue performance
- Excellent chemical and wear resistance
- Excellent long term performance under HPHT and sour gas conditions
- Easy to process and machine parts
- Flame retardance, low smoke and toxicity

Better seal performance with VESTAKEEP® PEEK

The ductile nature VESTAKEEP® PEEK offers the right performance combination for back-up rings and seals in a seal pack application. In such applications the elastic recovery of VESTAKEEP® PEEK leads to a perfect seal with no leakage. By comparison, competition PEEK's elastic recovery is much lower due to permanent plastic deformation normally associated with a less ductile material. VESTAKEEP® PEEK grades, thus offer exceptional performance under severe conditions such as chemicals (sour gas), high pressure, high temperature (HPHT), dynamic loads and complex assemblies.

VESTAKEEP® PEEK offers superior ductility, crack resistance, toughness, low temperature impact and higher mechanical performance at elevated temperatures than competitive PEEK grades.

14 – General properties of VESTAKEEP® PEEK for components

Property	Test method	Unit	VESTAKEEP® L 4000 G	VESTAKEEP® 5000 G	VESTAKEEP® 4000 GF30	VESTAKEEP® 4000 CF30	VESTAKEEP® 5000 CF30
Density [23°C]	ISO 1183	g/cm³	1.3	1.3	1.5	1.4	1.4
Melting range DSC [2nd heating]	ISO 11357	°C	approx. 340	approx. 340	approx. 340	approx. 340	approx. 340
Temperature of deflection under load							
Method A [1.8 MPa]	ISO 75-1	°C	155	155	312	325	324
Method B [0.45 MPa]	ISO 75-2	°C	205	205	335	335	338
Vicat softening temperature	ISO 306						
Method A [10 N]		°C	335	335	340	343	341
Method B [50 N]		°C	305	305	335	340	339
Linear thermal expansion [23 °C - 55 °C, longitudinal]	ISO 11359	10^{-4} K^{-1}	0.6	0.6	0.3	0.1	
Tensile test [50 mm / min]	ISO 527-1/-2						
Stress at yield		MPa	95	90			
Strain at yield		%	5	5			
Strain at break		%	25	35			
Tensile test [5 mm / min]	ISO 527-1/-2	MPa					
Tensile strength		%			160	240	230
Strain at break		%			2	2	2
Tensile modulus	ISO 527-1/-2	MPa	3500	3500	10800	23000	22500
Charpy impact strength	ISO 179/1eU						
[23°C]		kJ/cm²	N	N	70C	60C	59C
[-30°C]		kJ/cm²	N	N	75C	60C	
Charpy notched impact strength	ISO 179/1eA						
[23°C]		kJ/cm²	7C	9C	11C	11C	12C
[-30°C]		kJ/cm²	6C	8C	9C	9C	

15 - Oil and gas applications made from VESTAKEEP® PEEK

Application	VESTAKEEP® Grade
Back-up rings • Excellent creep, compression, dimensional stability and anti-cracking performance under severe conditions of HPHT and chemicals (sour gas), static or dynamic.	L4000G, 5000G, 4000GF30, 4000CF30
Other components – valve parts, downhole electrical connectors, switches, frac balls • High mechanical properties under HPHT conditions • Excellent resistance to chemicals such as, oils, seawater, sour gas (H_2S), hydraulic fluid • Excellent electrical insulation, dielectric strength, over wide range of temperatures	L4000G, 5000G, GF, CF and bearing grades
Seals, spring energized seals, face seals • Wear and abrasion resistance • Excellent HPHT performance • Chemical, sour gas resistance	L4000G, 5000G and filled grades
Pipes and liners • Excellent corrosion resistance • Chemical and mechanical performance • High temperature stability • Ductility and wear properties	5000G, custom grades
Umbilicals • Weight and cost reduction • Chemical resistance • Longer service life • Ductility, ease of processing	L4000G, 5000G
Subsea wire and cable jacketing, films • Inherently flame retardant • Long service life with consistent electrical properties under harsh environments and high temperatures • Hydrolysis, corrosion and abrasion resistance	4000HP, 5000G
Compressor parts – plates, rings packings and seals • High strength, stiffness and dimensional stability at wide temperature ranges • Wide range of chemical resistance – oils, acids, bases, hydrocarbons, organic solvents, salt solutions, water • Wear and abrasion resistance • Dynamic properties	L4000G, 5000G, 4000GF30, 4000CF30, 5000CF30, 4000FP, 5000FP
Coatings • Outstanding chemical, hydrolysis and corrosion resistance • Wear and abrasion • High temperature performance • Inherent flame retardant and electrical insulator	4000FP, 5000FP, 2000FP

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