Non Metallic Pipe for High Temperature High Pressure (HTHP) Applications & Recent developments in Polyamide 12 UV Resistance

April 2019 | Akshay Ponda
VESTAMID® NRG PA12
pipelines

Performance & Reliability

Experience

Standards & Safety
Who we are
Evonik at a glance

15 Billion Euro sales in 2018

176 Sites

>80% Of turnover gained from leading market positions

>36,000 Employees in over 100 countries

~230 New patent applications
Our Experience
Specialty chemicals with extensive experience in polymers

- ~ 160 years in Specialty Chemicals
- ~ 50 years in specialty long chain polyamides
- ~ 70 years in pipeline operations
High Performance Polymers Portfolio

Focus of HPP

- PA12
- PA1012
- PA612
- PA610
- PA1010
- PEEK
- PPA

Amorphous Crystalline

Cost Driven
Performance Driven

Commodity Polymers
Engineering Polymers
High Performance Polymers

= Polymers and semiinished products from Evonik Degussa

PET
PBT
POM
PA6 / PA66
PE
PE-LD
PE-HD

PPE
PMI
PPS
LCP
FPs
PAR
PSU
PI
PAI
PEI
PES
PM

Basic

Transparent PA

PA12
PA1012
PA612
PA610
PA1010
PEEK
PPA

PA612
PA6 / PA66

PES
PSU
PAR
PMMI
PS

PC
PMMA
PPI
PVC

ABS
SAN
PP
PUR
PE
PE-LD
PE-HD

PET
PEI
PPA
PA612
PA6 / PA66

Focus of HPP

Basic
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- PA610
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- PEEK
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Commodity Polymers
Engineering Polymers
High Performance Polymers

Cost Driven
Performance Driven

= Polymers and semi-finished products from Evonik Degussa
Offshore Experience

VESTAMID® NRG PA 12 is used in flexible pipes

“Thousands km of flexible pipes containing VESTAMID® NRG PA12 have been installed since 2006”
Our portfolio for the pipeline industry

- Flexible risers
- PA 12 Pressure pipe
- External steel pipe protection
- PA 12 Liners
- PEEK liners
- Reinforced thermoplastic pipe
- TCP
VESTAMID® PA12 - Performance

- VESTAMID® (PA12) is the material of choice for the fuel lines in cars since over 40 years.

- In 2014 so many automotive lines were produced from VESTAMID® (PA12) that the earth could be wrapped six times! (more than 240,000km).
VESTAMID® NRG PA12 is used in **flexible pipes** for reliable offshore operations since 2006.

Over 3000km of flexible pipes **VESTAMID® NRG PA12** have been installed since.
PA12 pipelines for high pressure natural gas distribution
PA12 liner system in Oil & Gas fields

Our main target: Pipelines operating at high temperature
Steel = Corrosion!

Old gas pipes prevalent in Ohio

Danger rises with increasing pipeline leaks, slow fixes

Alabama Gas Explosion Heightens Concern Over Cast-Iron Pipe Corrosion

Aging gas pipes pose explosion danger
PA12 saves investment costs:

- Project example:
  - PA12 110mm, SDR11
  - Steel 4” STD.

<table>
<thead>
<tr>
<th>Corrosion Costs: Total in 50 years</th>
<th>-100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection Costs</td>
<td>-100 %</td>
</tr>
<tr>
<td>Cathodic Corrosion</td>
<td>-100 %</td>
</tr>
<tr>
<td>Installation Costs</td>
<td>-90 %</td>
</tr>
<tr>
<td>Construction Costs</td>
<td>-12 %</td>
</tr>
<tr>
<td>Pipe &amp; Fittings</td>
<td>+122 %</td>
</tr>
</tbody>
</table>

![Bar chart showing cost comparison between PA12 and Steel](chart.png)
Installation of PA12 gas pipes is similar to state of the art PE pipe installation

- **PA12 pipes are coilable**
  - Reducing welding
  - Transport and handling are simplified

- **PA12 is easy to install**
  - Fast welding
  - Same machines and procedures as PE100
  - No need of field joint coating
  - No sand bedding
  - Ploughing
  - HDD

- **No corrosion**
  - No Cathodic Corrosion Protection
  - No maintenance
High pressure gas distribution pipelines

Pressure range between 100 and 250 psi
VESTAMID® NRG – Onshore Experience

USA:
- RTP: Polyflow
- GTI
  - DTE,
  - Atmos Energy
  - Energy West
  - National Fuel
  - WE-Energy Racine

Europe:
- TÜV & SKZ
- Westnetz/Innogy
- EON (Testing)
- Spain Approval

Mexico:
- United Pipeline systems
- GdF Suez - Testing

Brazil:
- SulGas
- MSGas
- CeGas
- Evonik

Canada:
- TAQA
- Evonik

Egypt:
- Town gas

KSA:
- Saudi Arabia - Approval

Indonesia:
- PGN
- EHK

Australia:
- 2018

Onshore liners

Evonik
## PA 12- Experience

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Characteristics</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy West, Montana, USA</td>
<td>Jul. 09</td>
<td>4” SDR 13.5</td>
<td>175 psig</td>
</tr>
<tr>
<td>Energy West, Montana, USA</td>
<td>Aug. 12</td>
<td>4” SDR 13.5</td>
<td>150 psig</td>
</tr>
</tbody>
</table>
## PA 12 - Experience

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Characteristics</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSGAS, Campo Grande, Brazil</td>
<td>Oct. 12</td>
<td>90 mm SDR 11</td>
<td>17 bar</td>
</tr>
<tr>
<td>MSGAS, Campo Grande, Brazil</td>
<td>Nov. 15</td>
<td>160 mm SDR 11</td>
<td>16 bar</td>
</tr>
</tbody>
</table>
VESTAMID® NRG PA12 has a long track record

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Characteristics</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surtigas, Cartagena, Colombia</td>
<td>Jun. 16</td>
<td>160mm SDR 11</td>
<td>16 bar</td>
</tr>
</tbody>
</table>

![Image of VESTAMID® NRG PA12 pipe production and installation](image_url)
**VESTAMID® NRG - Experience**

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Characteristics</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia</td>
<td>Dec. 16</td>
<td>110 mm SDR 11</td>
<td>16 bar</td>
</tr>
</tbody>
</table>

![Image of construction site with pipes and workers]

![Image of pipes laid in the ground]

![Image of workers installing pipes]

[Evonik logo]
Squeezed-off PA 12 pipe after 3 years service

Location: Gas Technology Institute, USA
Pipe Dimension: 4 inches, SDR 13.5
Pressure: 16 bar

<table>
<thead>
<tr>
<th>Performance</th>
<th>ASTM Specification</th>
<th>LHTS of 3-year Service Squeeze-off pipe at 2800 psi hoop stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours exposed</td>
<td>&gt;1000</td>
<td>2761 hours without failure of pipe</td>
</tr>
</tbody>
</table>

Squeeze-off Pipe
Squeeze-off of PA12 tested by E.ON, SKZ, KIWA and DBI

OD 110 & 160mm SDR 11 squeezed off at 5°C.

1. Technically tight.

2. No cracks on surfaces of squeezed off pipe. Only wrinkles with a depth of less than 1mm.

3. Squeezed off pipe tested under very sharp hydrostatic strength test. Similar results as non-squeezed-off pipe.

4. Pipe recovery is enough so that re-rounding might not be necessary.
Complete set of fittings is available in PA12

OD: 32, 63, 90, 110, 160mm; SDR 11

63-32, 90-32, 90-63, 110-32, 160-32; SDR 11

110-63, 160-63; SDR 11

63-32, 90-32, 63-63, 90-63, 110-63; SDR 11

160-63; SDR 11

OD: 32, 63, 90, 110, 160mm; SDR 11

90-63, 110-63, 110-90, 160-110; SDR 11

60 different parts !!
Butt and Electro Fusion of PA12 pipe is verified and standardized. ISO 16486 defines procedure and inspection criteria. Same procedure and machine as PE pipe.
Electrofusion of VESTAMID® NRG pipe is verified and standardized

ISO 16486 defines procedure and inspection criteria

Same procedure and machine as PE pipe.
DOT: VESTAMID® NRG
Pipe survives hitting test

PA12    HDPE
Latest UV Resistance Data on PA12

**Elongation at break from 100 % of start value**

**Viscosity Number from 100 % of start value**
VESTAMID® NRG PA12 Liners – trouble free corrosion protection

Case study:

Application

- Sour gas & condensate service
- High H2S concentration ca. 25 Vol.%
- Operating temperature ca. 50°C

Key issues solved

- Previous HDPE-liner experienced collapse due to **Permeation** and **Swelling**.
  - PA12: Lower permeation of gases
  - PA12: Very low swelling in hydrocarbons
  - PA12: No loss of mechanical strength in hydrocarbons
Multilayer liner with PE external layer and PA12 barrier layer

Combination of PE100 with VESRTAMID® NRG.

Case 1:
- Outer Layer : PE-RT
- Adhesive layer: grafted adhesive
- Inner Layer : VESTAMID® NRG
  Circumferential bonding strength = 221 N/cm
  Longitudinal bonding strength = 217 N/cm

Case 2:
- Outer Layer : PE100
- Adhesive layer: grafted adhesive
- Inner Layer : VESTAMID® NRG
  OD = 110 mm
Case study – Canada:
No degradation after 12 months in highly sour conditions

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Material</th>
<th>After 12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Modulus (at 1mm/min)</td>
<td>MPa</td>
<td>709</td>
<td>488</td>
</tr>
<tr>
<td>Tensile Stress at Yield (10 mm/min)</td>
<td>MPa</td>
<td>36</td>
<td>31</td>
</tr>
<tr>
<td>Tensile Elongation at Yield (10 mm/min)</td>
<td>%</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Stress at Break (10 mm/min)</td>
<td>MPa</td>
<td>37</td>
<td>36</td>
</tr>
<tr>
<td>Corrected Inherent Viscosity</td>
<td>dl/g</td>
<td>1.829±0.02</td>
<td>1.812±0.02</td>
</tr>
</tbody>
</table>
VESTAKEEP for O&G Pipe Applications

Akshay Ponda, Evonik USA
Polymers for Oil & Gas
PEEK & xPEEK for HPHT applications
PEEK – Basic Properties

- High Glass Transition Temp (Tg) $\rightarrow$ $\sim 143 - 152$ °C
- High Melting Point (Tm) $\rightarrow$ $\sim 340$ °C
- Continuous service temperature $\rightarrow$ $\sim 250$ °C
- Hydrolysis, hot water and hot steam resistance up to 250 °C
- High mechanical strength and rigidity
- Excellent resistance to chemicals.
- Outstanding wear and tribological behaviour.
- Inherent flame resistant (UL-V0, wall thickness independent)
- Good radiation resistance / highest gamma radiation resistance of all plastics
- Stress crack resistant very good friction and wear properties
Oil and Gas Application Overview

Exploration
Field Development
Production Operations

EXPLORATION
OIL & GAS

Transportation
Processing
Storage & Distribution

UPSTREAM
MID STREAM

FEEDSTOCK

DOWNSTREAM

Manufacturing
Refining & Petro-Chemicals
Wholesale & Marketing

SUPPORTING INDUSTRIES
Relative Properties of PEEK Polymer

Tensile Modulus (MPa)

Long term temperature resistance as per UL 746 (°C)

Temperature °C

Melting Point | Glass Transition Temperature

- Tg
- Tm
- HDT A
- HDT B

PA46
PA66
PA612
PA11
PA12
PPA
PBT
PEI
PEEK
PES
PPSU
LCP
**PEEK is ideal for demanding upstream applications**

**Current Applications:**
- Seal Packs – Back-up rings, face seals, etc
- Electrical Connectors, W&C Jacketing
- Anti wear tapes, Subsea Pipes and Liners
- Corrosion resistant coatings
- Parts for compressors, pumps, valves, etc.
- Tools, Subsea components
- Many more…

*Ref for above Chart: Schlumberger’s website. [www.slb.com](http://www.slb.com)*
Very high molecular weight PEEK exhibits higher strain at break at all temps…
Notched Impact Strength @ -65 to 100°C

- Higher the Molecular weight, better is the Impact resistance
Sour Fluid Resistance at Elevated Temperatures

- **NORSOK M710 Rev 2 testing:**
  - Test Temps – 195°C, 215°C, 225°C.
  - Exposure time – Up to 32 days

<table>
<thead>
<tr>
<th>Volume (%)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>10 (2) / 5 / 85 mol% H2S/CO2/CH4</td>
</tr>
<tr>
<td>10</td>
<td>Distilled Water</td>
</tr>
<tr>
<td>60</td>
<td>70 % heptane, 20% cyclohexane, 10% tolune</td>
</tr>
</tbody>
</table>

Exposure fluid composition and distribution

Results:

Vestakeep® 4000G and 5000G meet NORSOK Acceptance Criteria in terms of:

- Swell
- Tensile Properties – Changes in modulus, strength and elongation at break.

Ongoing work to test Vestakeep® grades under extreme conditions of exposure in temperature, chemical (very high % H2S / salt water) and time…
High Speed Impact Testing

- High speed penetration testing:
  - Piston is pushed through sample plate
  - Speed 1 m/s - 10 m/s
  - Force and elongation of sample recorded

<table>
<thead>
<tr>
<th>@ 23°C</th>
<th>PEEK 3</th>
<th>PEEK 4</th>
<th>PEEK 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m/s</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>4.4m/s</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>10m/s</td>
<td>D</td>
<td>D</td>
<td>B</td>
</tr>
</tbody>
</table>

- PEEK 4 – shows ductile fracture behavior due to a higher energy absorption
- High molecular weight PEEK also shows much less brittleness and thus does not fail in brittle mode.....
Summary: Molecular Weight Matters…

- **Very High Molecular Weight PEEK exhibits:**
  - Similar Mechanical Properties to other grades
  - Similar Chemical compatibility / resistance behavior
  - Higher Viscosity
  - Much less sensitivity to cracking (less brittle)
  - Potentially have an effect on overall long term performance and ultimate failure mode.
Regional standards for PA-U 12 180 are developing globally
VESTAMID® NRG PA12 improves the reliability of liners:
- High mechanical strength in Hydrocarbons
VESTAMID® NRG PA12 improves the reliability of liners:
- Low swelling in Hydrocarbons

- Better corrosion protection
- Pipeline venting frequency reduced ➔ OPEX savings
- Improved collapse resistance
VESTAMID® NRG PA12 – reliable liners in harsh conditions

- Low swelling in oil
- No loss of mechanical strength after saturation in oil
- Low gas permeation
- Improved collapse resistance
Grooved liner: active liner monitoring and leak detection system

1. The liner pipe was designed so that it could carry an annular space fluid used as a means for detecting damage to the steel without an actual leak developing.

2. A series of annular grooves were incorporated to the liner surface which carry air pressurized at 10 to 15 psi and monitored continuously.

3. In case a pinhole leak develops, the annular space pressure will drop indicating damage to the steel pipe while the liner bridges the hole and a possible leak.
2 layer system:

- **Inner layer**: modified PVDF (optimized bonding to PVDF).
  Provides chemical protection for PA12 layer (permeation, chemical resistance).

- **Outer layer**: PA12.
  Provides mechanical protection for PVDF layer (fatigue, ductility, creep).
VESTAMID® NRG PA12 Liners – trouble free corrosion protection

Case study:

24 Months operation

• No change in chemical properties of liner
• No loss in mechanical properties of the liner
• No swelling
• No venting of gases required

Value proposition of VESTAMID® NRG PA12

• Trouble free liner for corrosion protection in harsh conditions
• Collapse resistant liner with a design of more than 20 years