Thermoplastic Labyrinth Seals in Centrifugal Compressors - 15 years of experiences

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Thermoplastic Labyrinth Seals

- Thermoplastics used in compressors for over 20 years now.
- The two most common thermoplastic materials used are:
  - PolyAmide-Imide (PAI) – trade name Torlon
  - Polyetheretherketone – trade name PEEK
Thermoplastic Labyrinth Seals

Benefits of Thermoplastic Seals

- Efficiency
  - Design with reduced clearances

- Reliability
  - Maintain clearance during “transient” rubs
  - Forgiving during hard rubs (gall resistant)
  - Can be more corrosion resistant

- Ease of installation
Introduction

- Labyrinth Seals
  - Basics, leakage, use in centrifugal compressors
- Thermoplastics
  - Types, properties, use in centrifugal compressors
- Upgrade payback calculations
- Case Histories
  - Canadian ethylene plant
  - Texas ethylene plant
- Conclusions
Labyrinth Seals

- Seal an area of high pressure from an area of low pressure
- Clearance seals – they do leak
- Seals typically upgraded in a centrifugal compressor
  - Eye
  - Shaft or Hub
  - Balance piston
Labyrinth Seals – Compressor Seals

Return Channel

Diffuser

Note:
Arrows denote leakage paths.
Labyrinth Seals

Centrifugal compressor seal impact on efficiency.

Assume leakage is linear with clearance.
Assume 4% of the compressor efficiency loss is attributable to internal labyrinth seals.
If we reduce clearance to \( \frac{1}{2} \) then leakage will reduce to \( \frac{1}{2} \) --> 2% efficiency gain.
If all major compressors in a 2 billion lb/yr ethylene pant are upgraded this can save $700,000 per year in energy savings.
Labyrinth Seals

How to reduce seal leakage
- Reduce clearance and ensure it stays reduced
- Metallic seal rub can cause problems
  - Open seal bore
  - Vibration
  - Rotor damage (galling)
- Polymer seal rubs are “forgiving”
  - Clearance integrity
  - Not likely to induce rub related vibration
  - Typically do not damage rotor
Metallic Seal Rubs

- **As Installed:** Generous Radial Clearance
- **During Rub:** Deformed Teeth
- **After Rub:** Clearance Larger Than Installed
Polymer Seal Rubs

As Installed

Tight Radial Clearance

During Rub

Deflected Teeth

After Rub

Clearance Same as Installed
Thermoplastics

- Define Thermal Property Terms
- Polymer Types
  - Thermosets
  - Thermoplastics
    - Amorphous
      - Torlon®
    - Crystalline
      - PEEK
Thermoplastics

Thermal Properties

- Tg – Glass transition temperature
- Tm – Melt temperature
- CUT – Continuous Use Temperature
- HDT – Heat Deflection Temperature
- DMA – Dynamic Mechanical Analysis
- CLTE – Coefficient of Linear Thermal Expansion
Thermoplastics

- Tg – Glass transition temperature
  - Temperature at which the polymer softens
  - Below Tg polymers are rigid
  - Above Tg polymers are “rubbery”
  - At Tg CLTE increases significantly
  - Above Tg strength and modulus drop off
  - Loses “memory”
  - For labyrinth seals operation at or above the Tg should be avoided.
**CUT** – Continuous use temperature

- Based upon UL tests
- Temperature a polymer can be exposed to for 100,000 hours before losing ½ its strength.
- Accounts for thermal aging
- Increases brittleness
- Does not impact installed seal performance
- Only a concern in high temperatures (300-350 °F)
HDT is the Heat Deflection Temperature

Per ASTM D-648, the temperature at which a standard test specimen (typically 0.5” W x 5” L x 0.5” Thick) under a load of 264 psi will deflect 0.010” or 5%

Essentially the HDT is the temperature at which the flexural modulus of the polymer is reduced to 100,000 psi.

DMA (Dynamic Mechanical Analysis) is a measure of the stiffness at temperature.
DMA Plot for Various Thermoplastics

Temperature (°F)

Dynamic Modulus (ksi)

- PEEK (15% CF)
- Torlon (0% CF)
- Torlon (30% CF)
- Fluorosint
Thermoplastics

- CLTE (Coefficient of Linear Thermal Expansion)
  - Describes how the size of a part will change with changes in temperature.
  - The smaller the material’s CLTE, the more dimensionally stable a part made from that material will be as temperatures are varied.
  - For most polymers the CLTE increases with temperature.
  - Must be accounted for in close tolerance applications.
CLTE Plot

The graph shows the coefficient of thermal expansion (CLTE) as a function of temperature for different materials. The x-axis represents temperature in °F, ranging from -200 to 600. The y-axis represents CLTE in inches per inch per degree Fahrenheit, scaled by $10^{-6}$. The graph includes lines for Torlon, Aluminum, PEEK (30% CF), and PEEK (15% CF).
Relative Thermal Properties

- 

<table>
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<tr>
<th></th>
<th>Tm</th>
<th>HDT</th>
<th>Tg</th>
<th>CUT</th>
<th>PEEK</th>
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<tbody>
<tr>
<td>°F</td>
<td>695</td>
<td>518</td>
<td>289</td>
<td>500</td>
<td>392</td>
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Thermoplastics

- Chemical Attack Depends on
  - Temperature
  - Concentration
  - Pressure
  - Time
As a Semi crystalline polymer, PEEK is highly resistant to chemical attack **BUT** will be attacked by concentrated (over 30%) strong acids at high temperature:

**Sensitive to:**
- Chromic Acid
- Hydrofluoric Acid
- Nitric Acid
- Sulfuric Acid
- Chlorine Dry & Wet

**Unaffected by:**
- Acetic Acid, 10% Conc
- Amines
- Hydrocarbons
As an amorphous polymer, Torlon is less chemically resistant than PEEK.

**Sensitive to:**
- Amines (-NH2)
- Ammonia (-NH3)
- Oxidizing Acids
- Strong Bases (OH)
- Chlorine Dry & wet
- Saturated Steam
  - > 300F

**Unaffected by:**
- Automotive Trans. Fluids
- Aliphatic Hydrocarbons (Butane)
- Aromatic Hydrocarbons (Toluene)
- Halogenated Hydrocarbons
  - such as: Methylene Chloride
Data required includes:

- Process make up for compatibility analysis
- Suction and discharge temperatures and pressures
- Speed – for centrifugal growth calculations
- Cross sectional drawing of compressor showing impeller and seal arrangement
- Actual sealing diameters, from recent inspection report
- Sample seals or seal drawings
- Bearing clearance
Calculations performed:

- Polymer properties at operating temperature
- Thermal expansion of impeller, seal, and diaphragm
- Centrifugal growth of sealing surface
- Resulting operating seal clearance
  - Size operating clearance equal to bearing clearance
  - For barrel compressor use 1.5 times bearing clearance
Low temperature applications

- Since CLTE is high the seals will contract more than surrounding components – this must be accounted for.
- Must ensure “hook” will not bind up in diaphragm.
- Successfully applied by authors at negative 150 degrees F suction temperature.
- Extrapolate mechanical properties.
Tensile Strength vs. Temperature

![Graph showing Tensile Strength vs. Temperature for different materials: Torlon, PEEK (30% CF), Aluminum, and PEEK (15% CF).]
Tensile Modulus vs. Temperature

![Graph showing Tensile Modulus vs. Temperature for different materials.](image-url)
Compressive Strength vs. Temperature

![Graph showing compressive strength vs. temperature for Torlon and Aluminum]
A common “rule of thumb” for estimating compressor performance gains is to use ¼ to ½ % per impeller. Based upon experience this is conservative. Use the ½% number if the balance piston seal is included in the project.
Upgrade Payback Calculations

- Items brought up during this discussion;
  - “I expect to see efficiency gains after a turnaround.”
  - How to break out overall gains when several things were done that should improve efficiency.
  - “I can’t measure my compressor efficiency accurately enough to quantify the gains.”

- Use past experience
  - See the two case histories that follow.
Case Histories

Case 1: Canadian Ethylene Plant

  - 10th Ethylene producers conference

- Whalen and Miller: “An ethylene plant benefits from polymer labyrinth seals.”
  - Turbomachinery International, 1998

Case 2: Texas Ethylene Plant

- Whalen and Dugas: “Upgrading centrifugal compressors with polymer seals in an ethylene plant – a case history.”
  - 29th Turbomachinery Symposium, 2000
1996 Outage – Ethylene 1
- Installed Torlon in two cracked gas compressors and the propylene compressor
- Propylene seals are very large
  - 45” bore 1st stage eye, 36 ½” bore balance piston
Canadian Ethylene Plant

- Ran 4 years - to 2001
  - Checked clearances in one machine – still in spec
  - Buttoned up and running today

- Ran 5 years - to 2006
  - Checked clearances – still in spec
  - Buttoned up and running today
  - Expect to run for 6 years
1998 Outage – Ethylene 2
Installed Torlon in all three cracked gas compressors and the ethylene compressor
2002 outage – still in spec
2007 outage – still in spec
All major compressors in both units are now running polymer seals.
Canadian Ethylene Plant 1996 outage
Canadian Ethylene Plant 1996 outage
Historical trouble fitting the babbitt lined balance piston seal
- Machined teeth off balance piston
- Went with Torlon stationary teeth

Significant reduction in installation time

No drop in performance
Torlon Tooth Scrapping Tool

Relatively clean service but some seals were fouled
Shaft Seal as removed after 4 and 5 year runs - 9 year total run time - reinstalled will run another 6 years.
Eye Seal as removed after 4 and 5 year runs – 9 year total run time
Some seals were damaged when removed
These (5) were sent to vendor for analysis
  All from charge gas service
Vendor found very little drop off in properties
  Seals ran for 9 years
  Visually looked good
  Slight embrittlement
  Tg constant – no polymer degradation
Reported:

“…2-3% increase per compression stage with the installation of thermoplastic seals.”

“The rotating equipment specialists at the Joffre site believe that the use of thermoplastics is important in optimizing performance, increasing run lengths, and reducing turn around costs.”
Texas Ethylene Plant

- Major ethylene producer
- Has six primary compressor trains
  - Booster
  - Charge gas (3 bodies)
  - Propylene refrigeration (2 bodies)
  - Ethylene refrigeration
  - Purge propylene
  - Methane (2 bodies)
DuPont Cracked Gas Train
DuPont Cracked Gas Train

36,000 hp turbine driving three compressor bodies

Upgraded 1\textsuperscript{st} stage and 2\textsuperscript{nd}/3\textsuperscript{rd} stage compressors in 1999

Also upgraded both propylene, the ethylene, and the purge propylene compressors in 1999

Upgraded last case in 2005
Texas Ethylene Plant

n Introduction to polymer seals
  q Started investigating early 1990’s
  q Talked to several users
  q Decided to upgrade and evaluate one compressor
    n 10,000 hp booster
    n Upgraded in 1997
Texas Ethylene Plant

- Booster compressor
  - Plant can run w/o booster
  - Used 3% efficiency upgrade for justification
  - Installation went smoothly (only real work performed that would effect efficiency)
  - After upgrade realized:
    - 3.1% flow increase
    - 2.7% steam flow reduction
  - Decided to upgrade remaining compressors
New Polymer Seal– Newly Coated Rotor
New Polymer Seal–Newly Coated Rotor
Texas Ethylene Plant
Used Booster Compressor Shaft Seal
Texas Ethylene Plant
Used Charge Gas Compressor eye Seal
Texas Ethylene Plant

- Fouling more of an issue at this facility
- Replaced charge gas seals in 2003 and 2008
  - Too fouled and could not clean
- Inspected and reused refrigeration compressor seals in 2008
  - Very clean service
  - 9 year run (since 1999)
  - Seals “in spec”
Texas Ethylene Plant

Conclusions

- It is estimated that overall plant capacity increased 5% due to the polymer seal upgrades.
- Reliability increased due to forgiveness of polymer seals compared to aluminum.
- Plant is extremely pleased with this upgrade project.
The cases presented here represent up to 15 years of experience running polymer seals in critical turbomachinery. Analysis of material removed from service after 9 years demonstrated very low levels of material degradation. Indeed other seals were reinstalled and will run for another 6 years or longer before being reevaluated.
Thermoplastic Seals

- Labyrinth Seals
- Thermoplastics
- Engineering an Upgrade
- Upgrade payback calculations
- Case Histories
  - Canadian ethylene plant
  - Texas ethylene plant
- Conclusions
DISCUSSION GROUP T1
ON
TURBOMACHINERY OPERATION AND MAINTENANCE

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