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

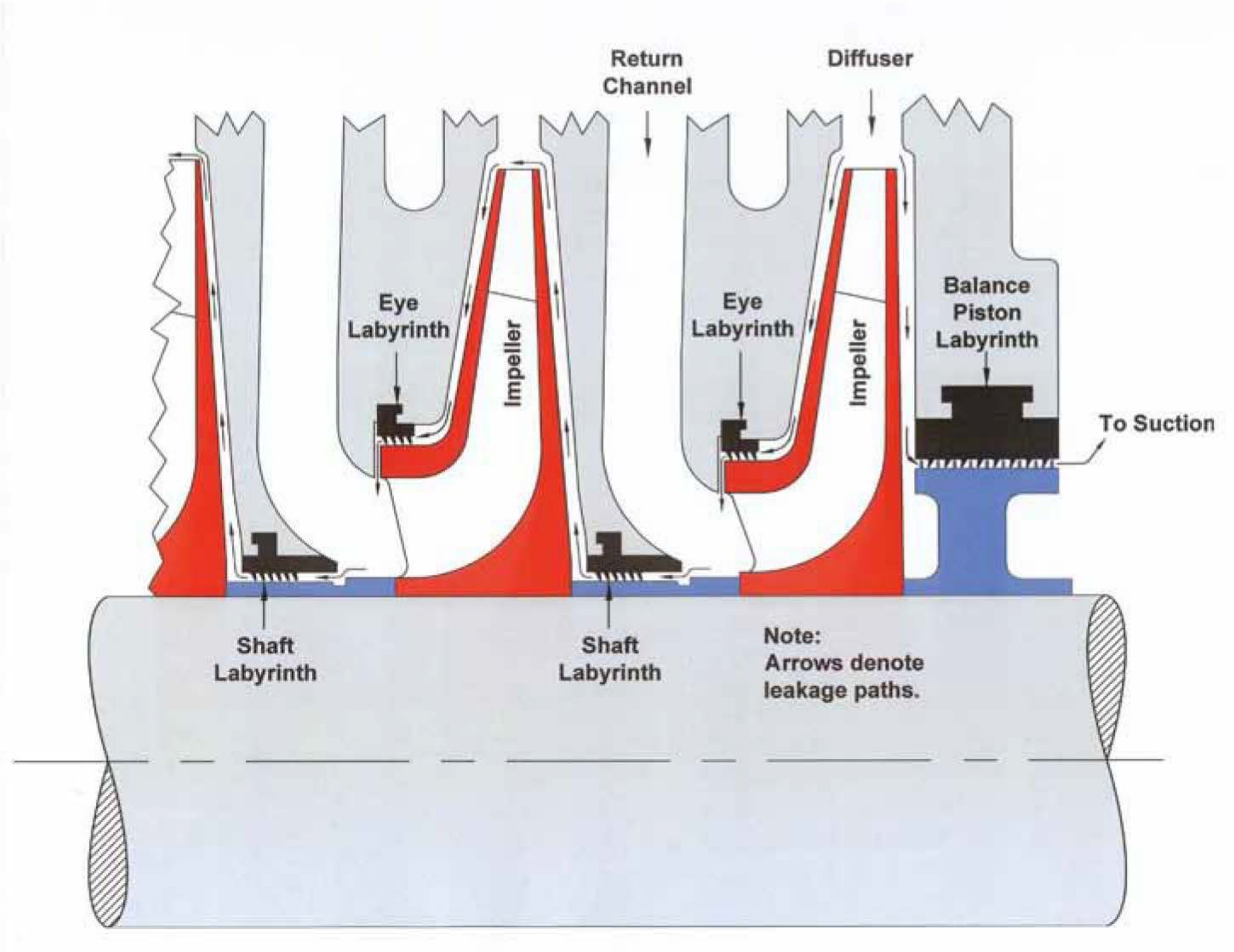
Introduction

- 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



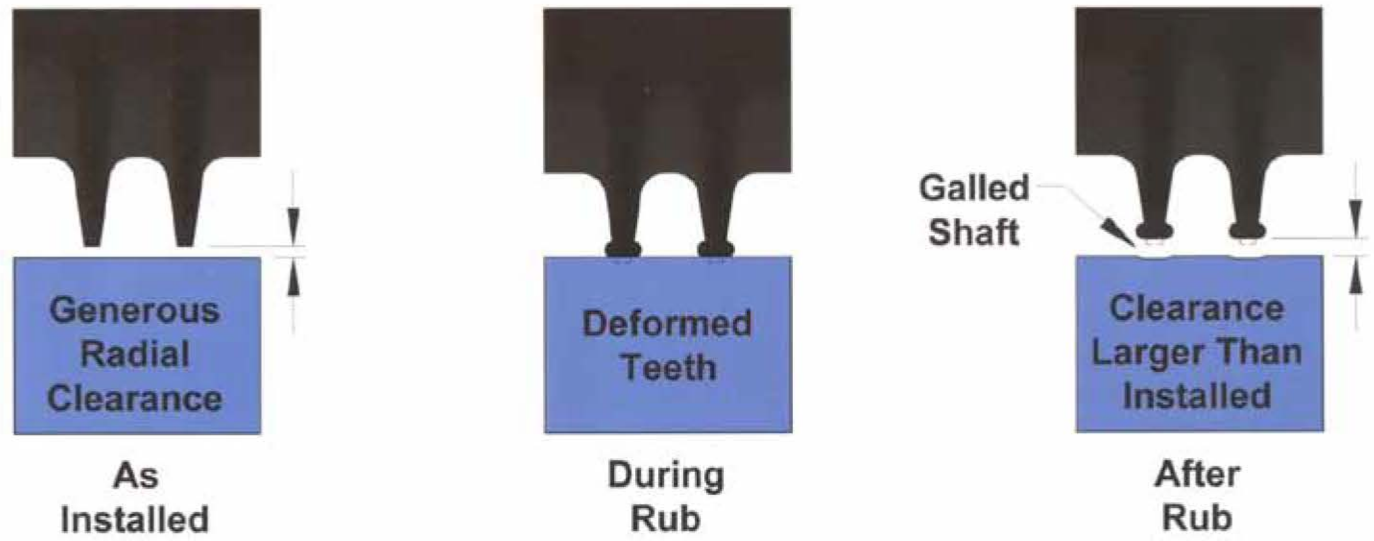
Labyrinth Seals

- 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 ½ then leakage will reduce to ½ --> 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.

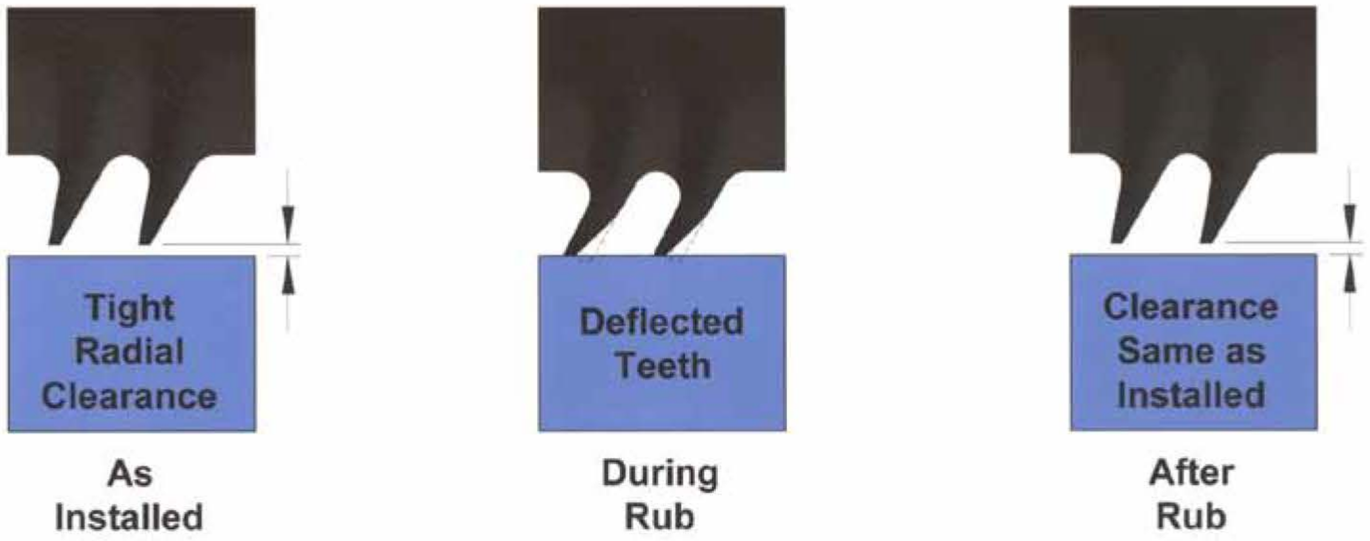
Labyrinth Seals

- 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



Polymer Seal Rubs



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.

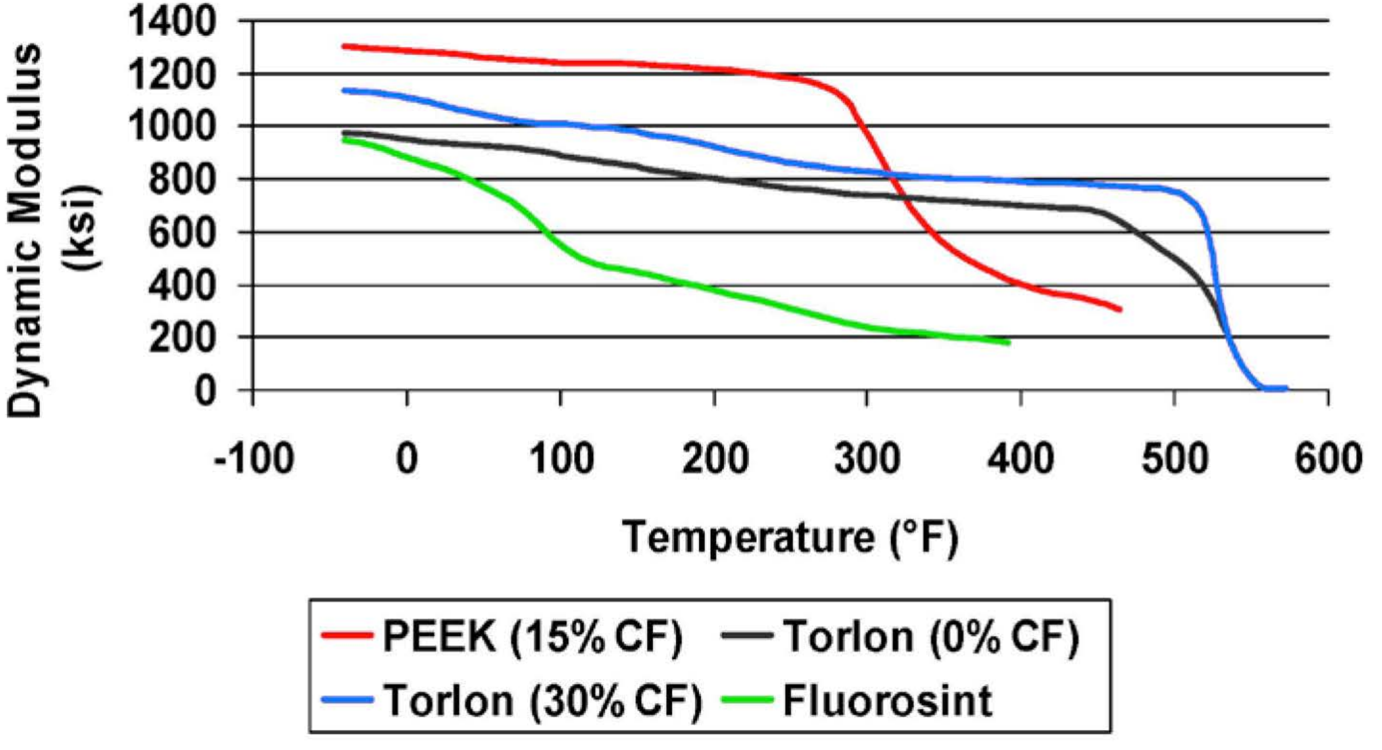
Thermoplastics

- 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 ºF)

Thermoplastics

- 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.

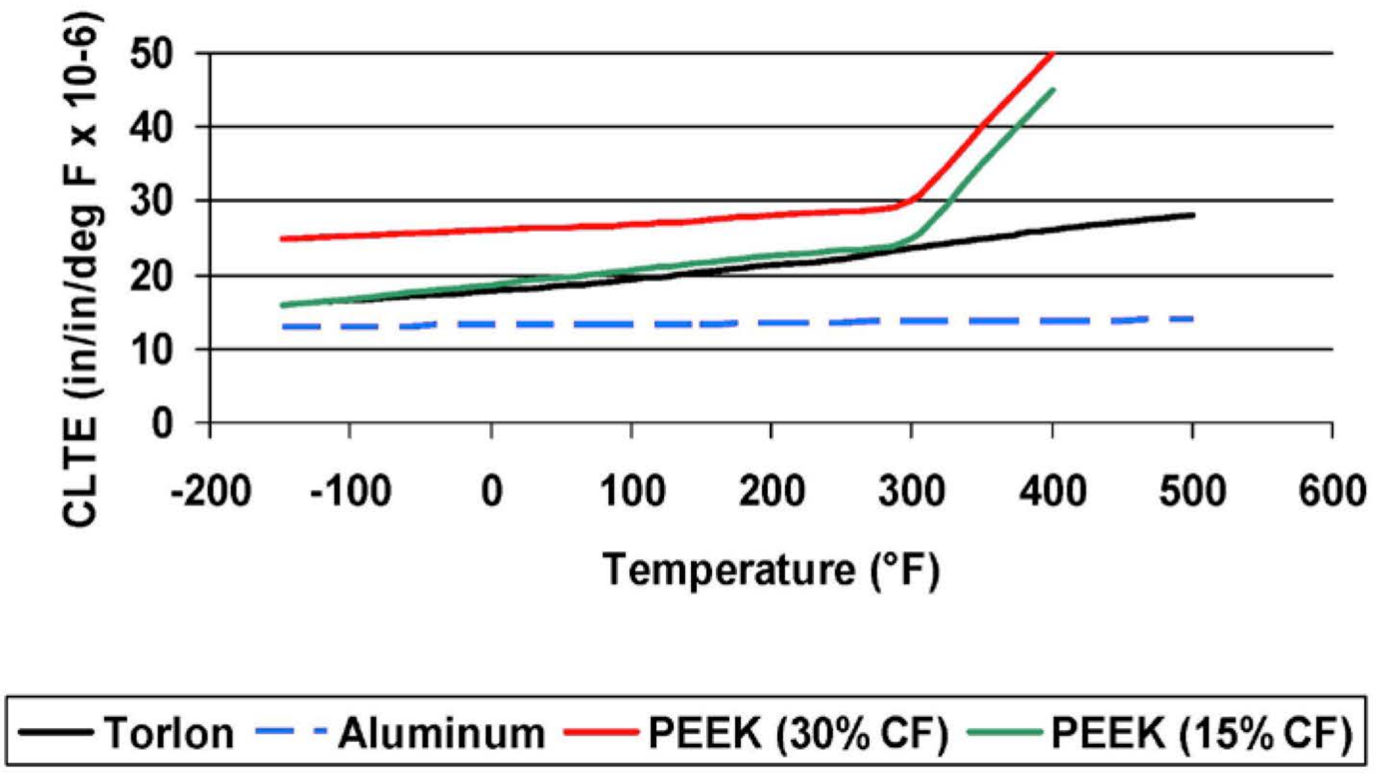
DMA Plot for Various Thermoplastics



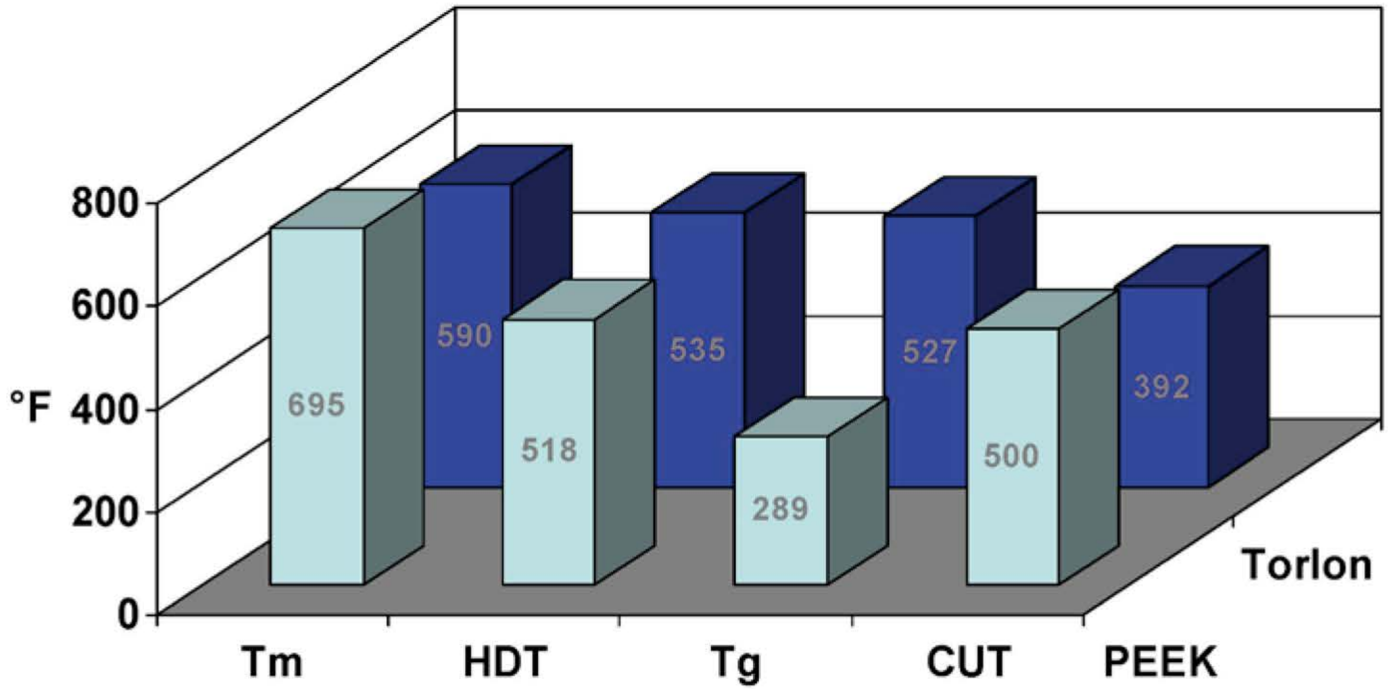
Thermoplastics

- 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


CLTE (in/in/deg F x 10-6)
50
40
30
20
10
0
-200
-100
0
100
200
300
400
500
600
Temperature (°F)
Torlon
Aluminum
PEEK (30% CF)
PEEK (15% CF)

Relative Thermal Properties



Thermoplastics

- Chemical Attack Depends on

  Temperature

  Concentration

  Pressure

  Time

PEEK Chemical Resistance

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

Torlon Chemical Resistance

As an amorphous polymer, Torlon is less chemically resistant than PEEK.

Sensitive to:	**Unaffected by:**
Amines (-NH2)	Automotive Trans. Fluids
Ammonia (-NH3)	Aliphatic Hydrocarbons(Butane)
Oxidizing Acids	Aromatic Hydrocarbons (Toluene)
Strong Bases (OH)	Halogenated Hydrocarbons
Chlorine Dry & wet	such as: Methylene Chloride
Saturated Steam	
> 300F	

Engineering

- 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

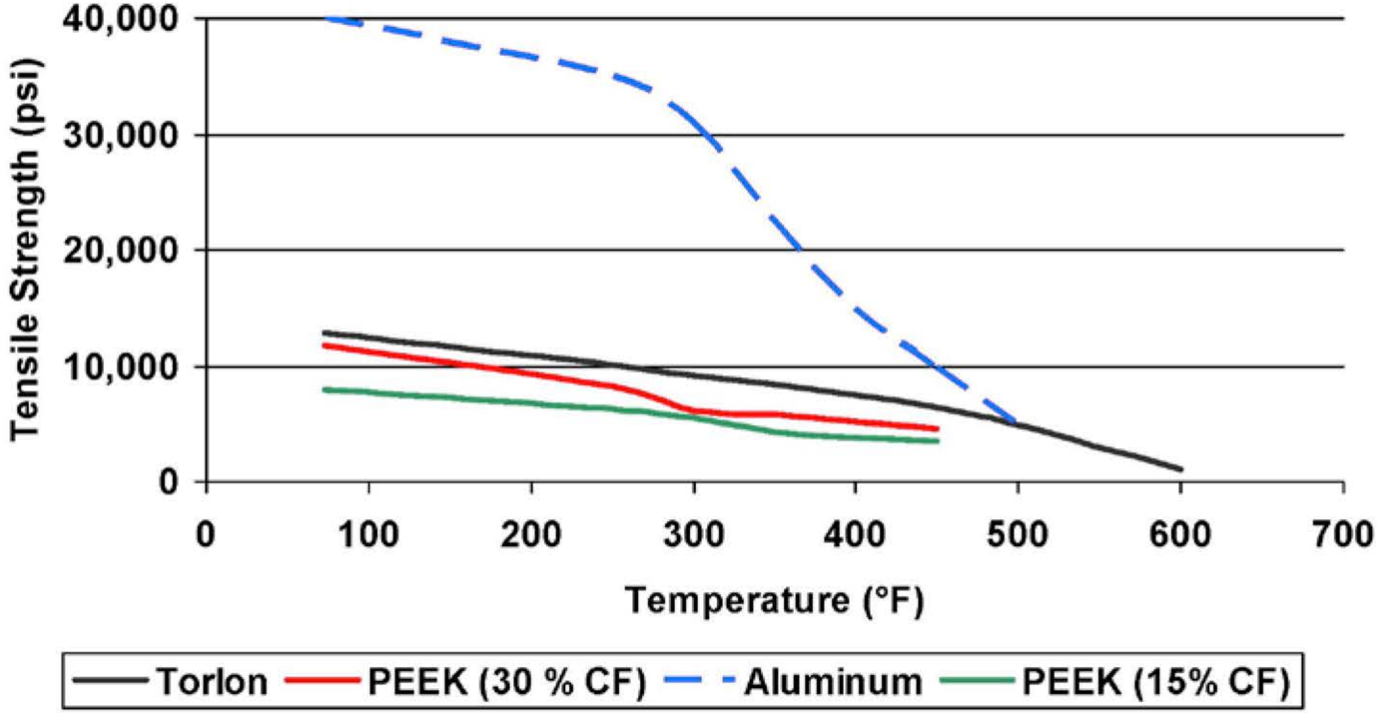
Engineering

- 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

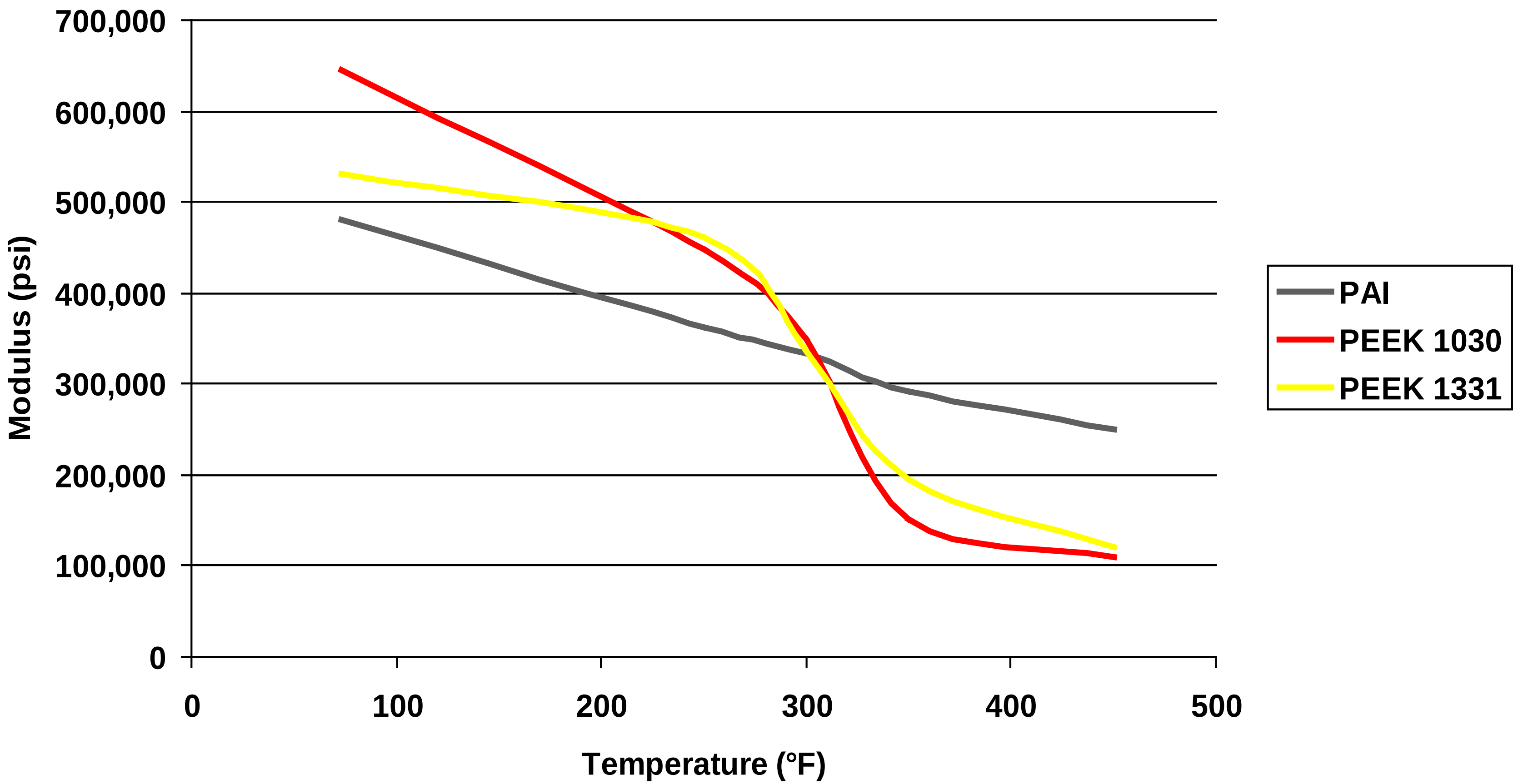
Engineering

- 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.

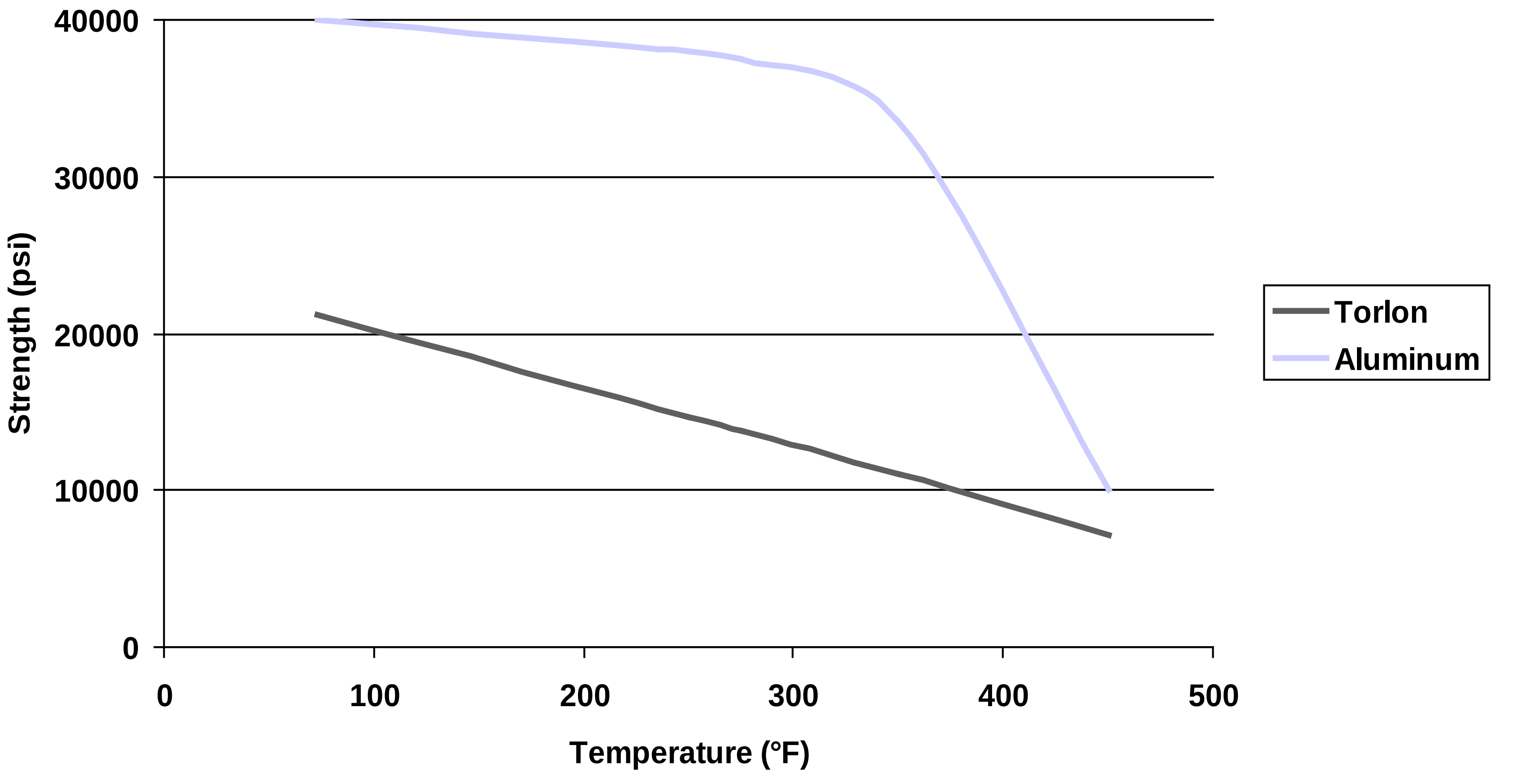
Tensile Strength vs. Temperature



Tensile Modulus vs. Temperature



Compressive Strength vs. Temperature



Upgrade Payback Calculations

- 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
  - Chow and Miller: “Optimizing performance of an ethylene plant cracked gas compressor train.”
    - 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

Canadian Ethylene Plant

- 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

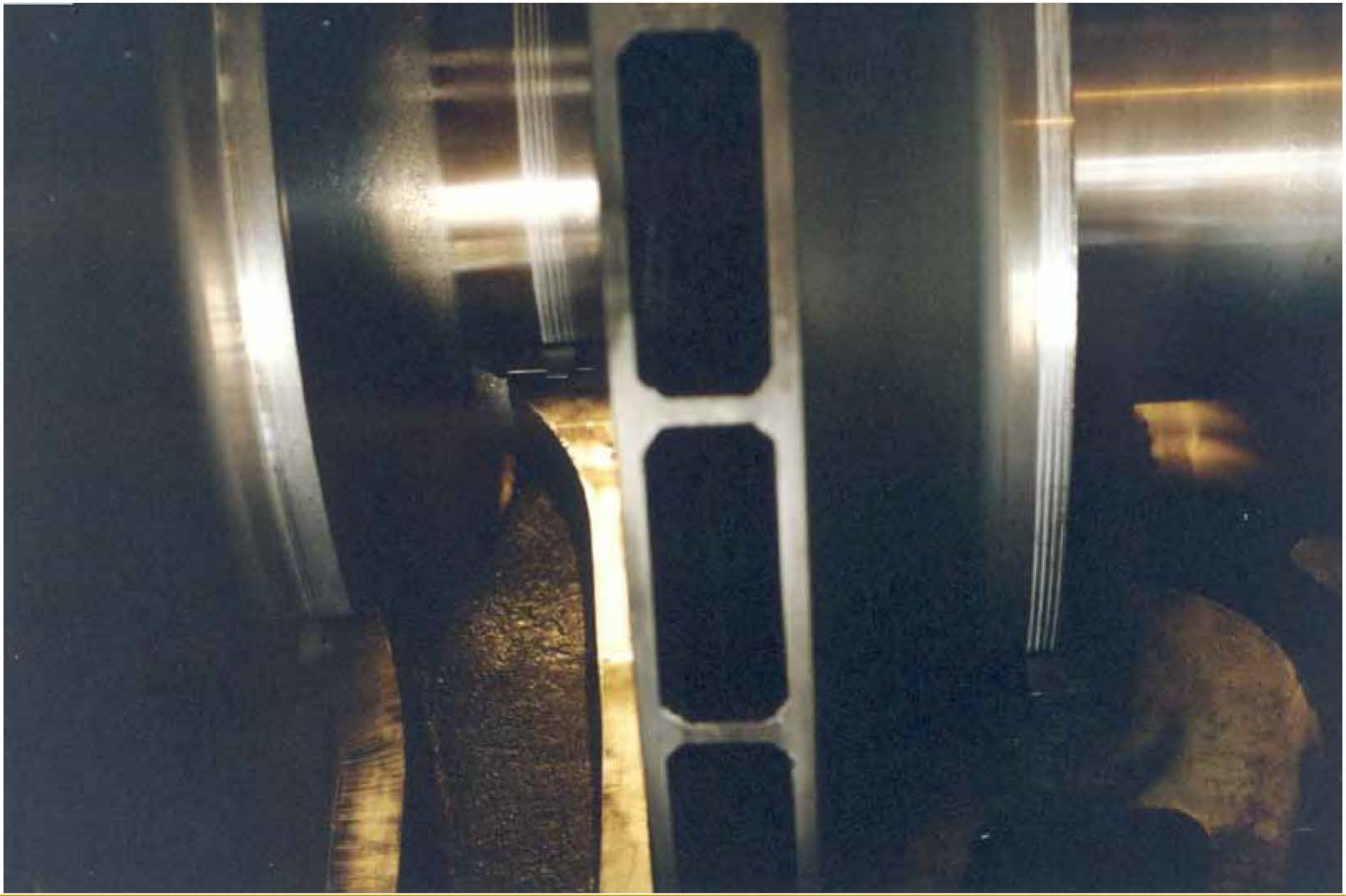
Canadian Ethylene Plant

- 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

Canadian Ethylene Plant

- 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

Canadian Ethylene Plant

- 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

Canadian Ethylene Plant

- 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

Canadian Ethylene Plant

- 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

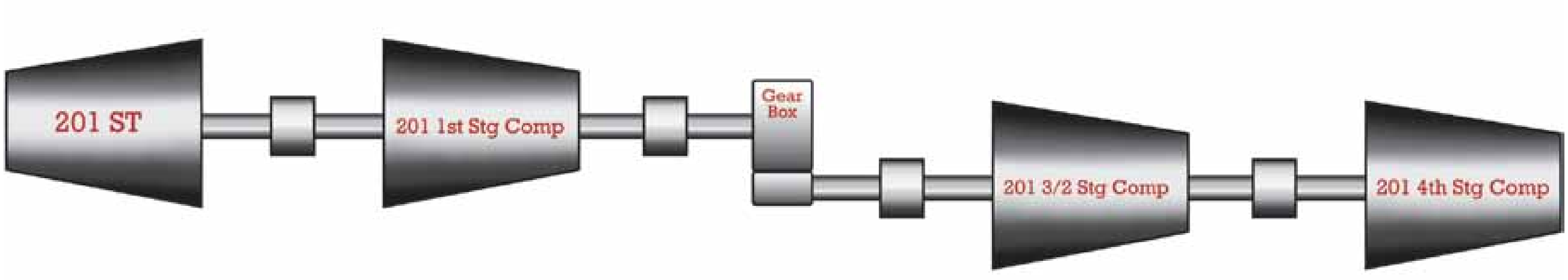
- Major ethylene producer
- Has six primary compressor trains
  - Booster
  - Charge gas (3 bodies)
  - Propylene refrigeration (2 bodies)
  - Ethylene refrigeration
  - Purge propylene
  - Methane (2 bodies)

DuPont Cracked Gas Train

DuPont Cracked Gas Train

36,000 hp turbine driving three compressor bodies

Upgraded last case in 2005



Upgraded 1st stage and 2nd/3rd stage compressors in 1999

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

Texas Ethylene Plant

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

Texas Ethylene Plant

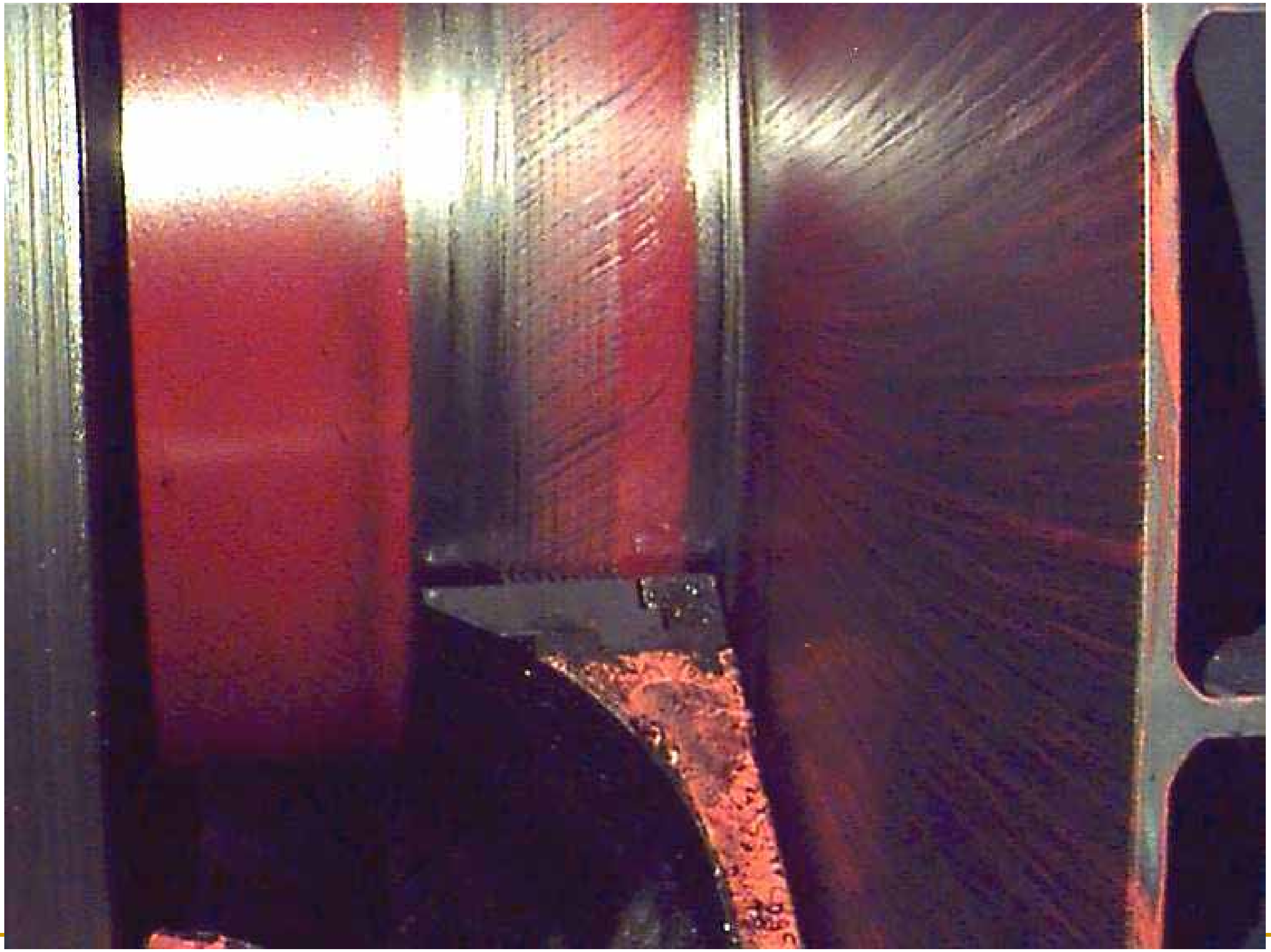
- Booster compressor
  - Plant can run w/o booster
  - Used 3% efficiency upgrade for justification
  - Installation went smoothly (only real work performed that would effect efficiency)
  - After upgrade realized:
    - 3.1% flow increase
    - 2.7% steam flow reduction
  - Decided to upgrade remaining 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

Conclusion

- 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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