51ST TURBOMACHINERY & 38TH PUMP SYMPOSIA
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Ethylene Product Pump
Mechanical Seal Design Enhancements Through Advanced Analysis

Brian Kalfrin – John Crane
Doron Or – John Crane
Justin Fudge – Nova Chemicals

john crane

NOVA Chemicals

Authors:

Doron Or

Doron graduated from the Technion – Israel Institution of Technology in 1998 with a B.Sc. in Chemical Engineering. Worked for 6 years as a Customer Service and Quality Manager for John Crane Distributor's in Israel, dealing with Mechanical Seals' application engineering and troubleshooting in a variety of industries including: Oil & Gas, Chemical, Mining, Pharmaceutical, Food, Pulp and Paper. Joined John Crane Canada in 2002 , as a Technical Sales Rep, servicing customers in Oil & Gas, Petrochemical, Chemical and Pipeline. Doron embraces continuous improvement in troubleshooting, application engineering, materials and design in order to increase seal MTBR. He has over 26 years of extensive field experience with mechanical seals and related systems.

Brian Kalfrin

Brian Kalfrin is a Senior Regional Engineering Manager with John Crane in Pasadena Texas with over 21 years of experience with mechanical seals and related systems. He is responsible for engineering expertise within the North American Region for John Crane. His duties include design engineering oversight, analysis, and recommendation formulation to address challenging problem applications, along with design evaluation of existing and proposed mechanical seals utilizing Finite Element Analysis (FEA) software. He is also responsible for training of both customers and John Crane personnel in both mechanical seal application and troubleshooting. Mr. Kalfrin is a member of the Texas A&M International Pump Users Symposium Advisory Committee, the API 682 Task Force currently working on the 5th Edition, and a degreed Mechanical Engineer with a BSME from Drexel University in Philadelphia, PA.

Justin Fudge

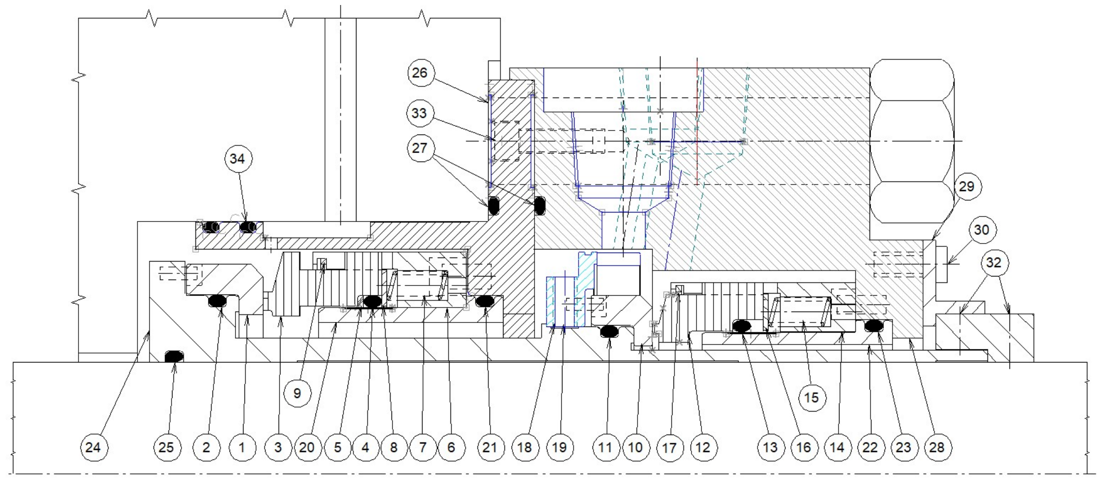
Justin Fudge is a Rotating Equipment Specialist with 17 years of experience in rotating equipment and engineering, the entirety of which has been with Nova Chemicals. Justin received his Millwright R.S.E. from NAIT in 2009 and spent 10 years in plant maintenance before transitioning into a technical role in 2019. Justin has spent most of his career in Polyethylene production where he gained vast experience troubleshooting and implementing solutions to a wide variety of rotating equipment problems.

Abstract:

One of the largest ethylene and polyethylene production complexes in the world located in Alberta Canada was dealing with marginal reliability of the mechanical seals on their ethylene product pumps. The ethylene product pumps are classified as API 610 BB5 types and the duty conditions for the mechanical seals are arduous, experiencing seal chamber pressures continuously above 1000 PSIG at sub-zero temperatures. The pumps operate at shaft speeds above 5,000 RPM providing additional challenges for the mechanical seal to overcome. The heritage mechanical seals utilized in this application were a dual unpressurized configuration supported by an API Piping Plan 11 and 52. Through close collaboration with the end user, the supplied seal provided by the manufacturer was able to achieve an 18 – 24 Mean Time Between Repair (MTBR). Known failure modes of the existing mechanical seal identified during failure analysis activities were addressed through modification of the seal to the existing iteration. The most recent limiting factor in seal performance was attributed to breakdown of the dynamic secondary sealing element in both the process and containment seals. The dynamic secondary seal, or o-ring, experienced a high degree of abrasion and breakdown. It was the seal manufacturer's recommendation to address the root cause of seal failures by proposing an alternative configuration. The alternative seal configuration utilized active seal face features for optimized sealing of the ethylene while incorporating a non-pusher secondary seal (NPSS) to both the process and containment seals to address the dynamic o-ring concerns. Additionally, improvements to the circulation and cooling of the Plan 52 loop were identified and optimized through CFD modeling of the internal circulation device and support system piping. All modifications were incorporated into a redesigned seal cartridge that was installed during a unit outage in September 2021. Performance of the new design to date has been extremely satisfactory despite several documented upsets in the process stream.

Original Mechanical Seal:

Application Details and History:
Reactor Feed Pump
Sulzer CP, 12 stages barrel pump, BB5



Process Fluid:	Ethylene
Temp:	-25C/-13F
Seal Chamber Pressure:	1,102 psig
SG:	0.446
Vapor Pressure @PT:	322 PSIA
Speed:	> 5,000 RPM

Original Mechanical Seal:

- O-Ring, Pusher, Balanced seal, Hydro-Pads,
- Carbon Vs Silicon Carbide Faces
- Low Temp Viton Elastomers.
- Paddle Wheel Pumping Ring

Original Mechanical Seal:

Application Details and History:

- Original seal's MTBR was 18-24 months.

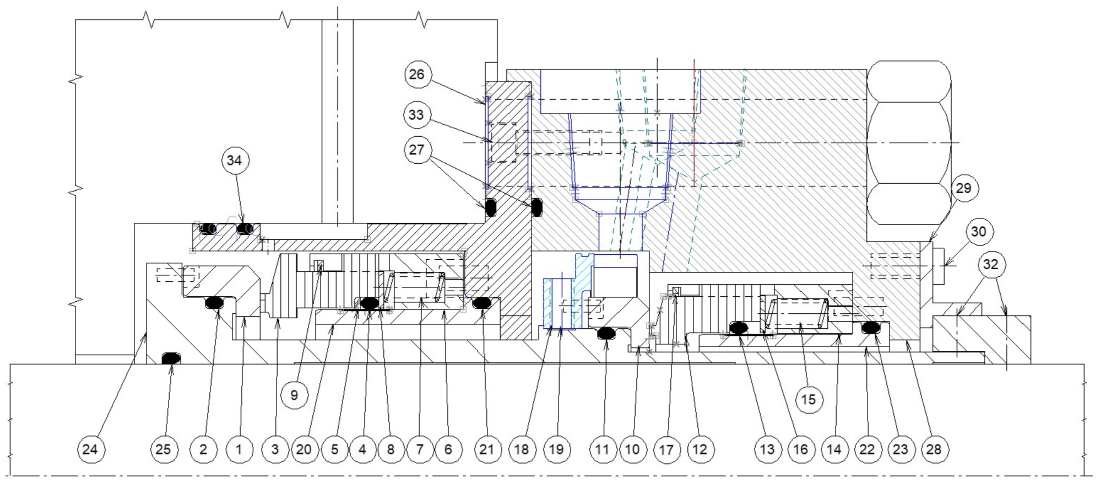
Typical Failure Symptoms were:

Primary Seal:

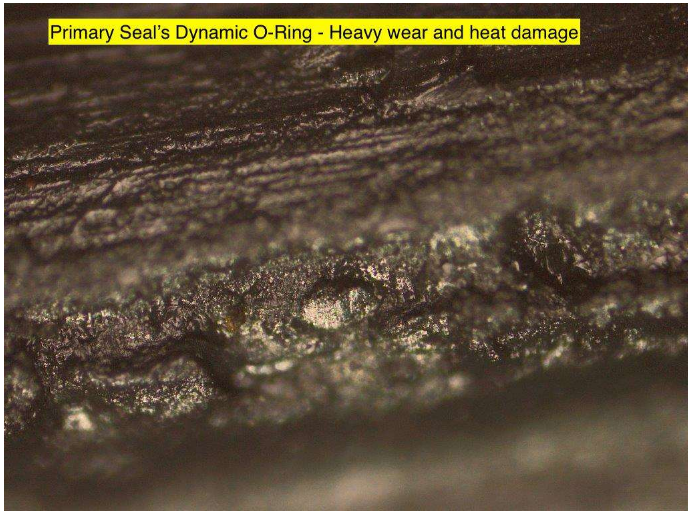
- Extreme ID wear and ID chipping
- Dynamic O-Ring Fretting, O-Ring damage and hang-up
- Polymerization of the process fluid at the seal faces

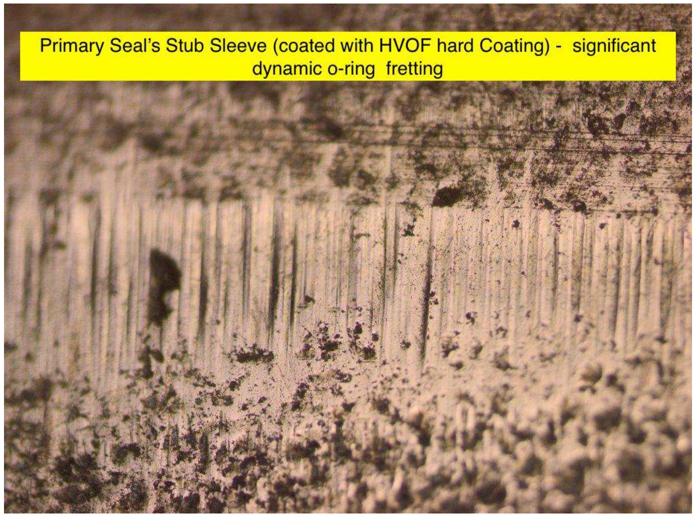
Secondary Seal:

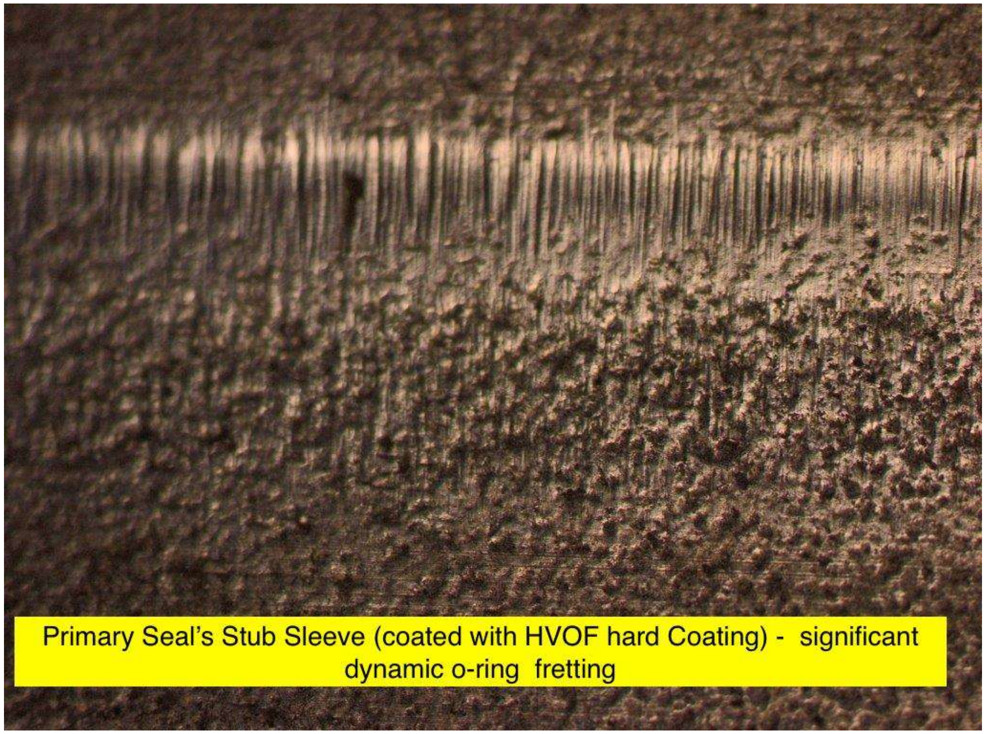
- Dynamic O-Ring hang-up and fretting, Mating Ring O-Ring heat damage
- Primary Ring face wear, grain pullout and ID chipping



The original seal's failure modes/symptoms:







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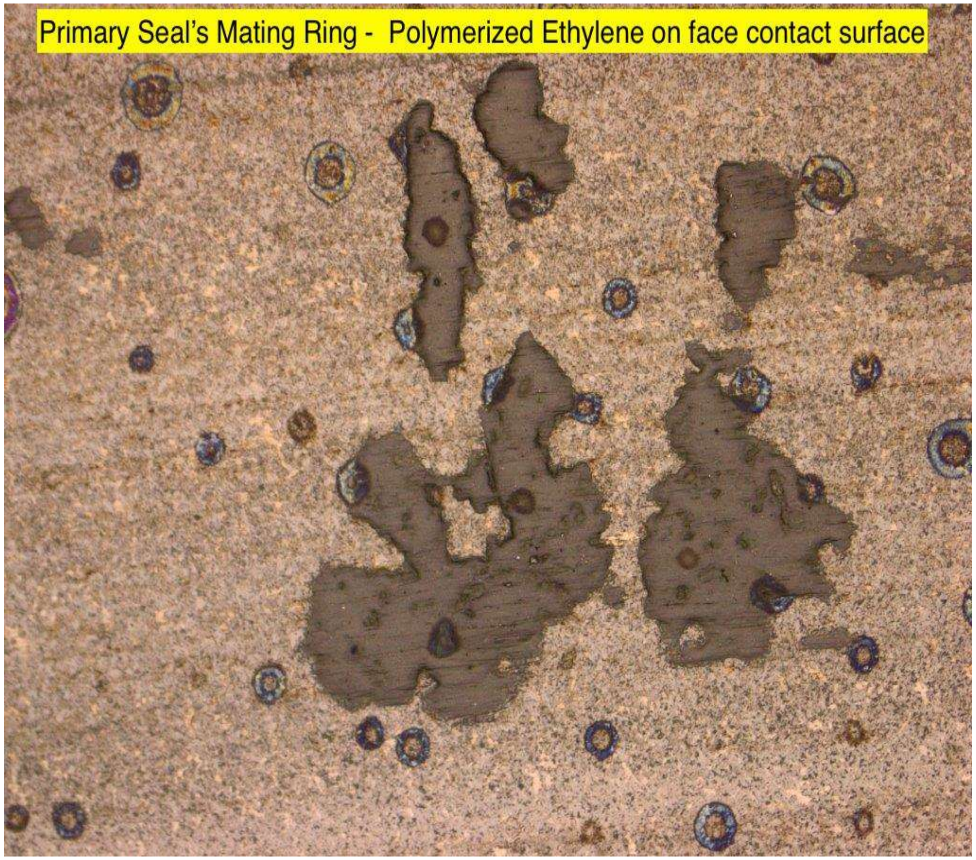

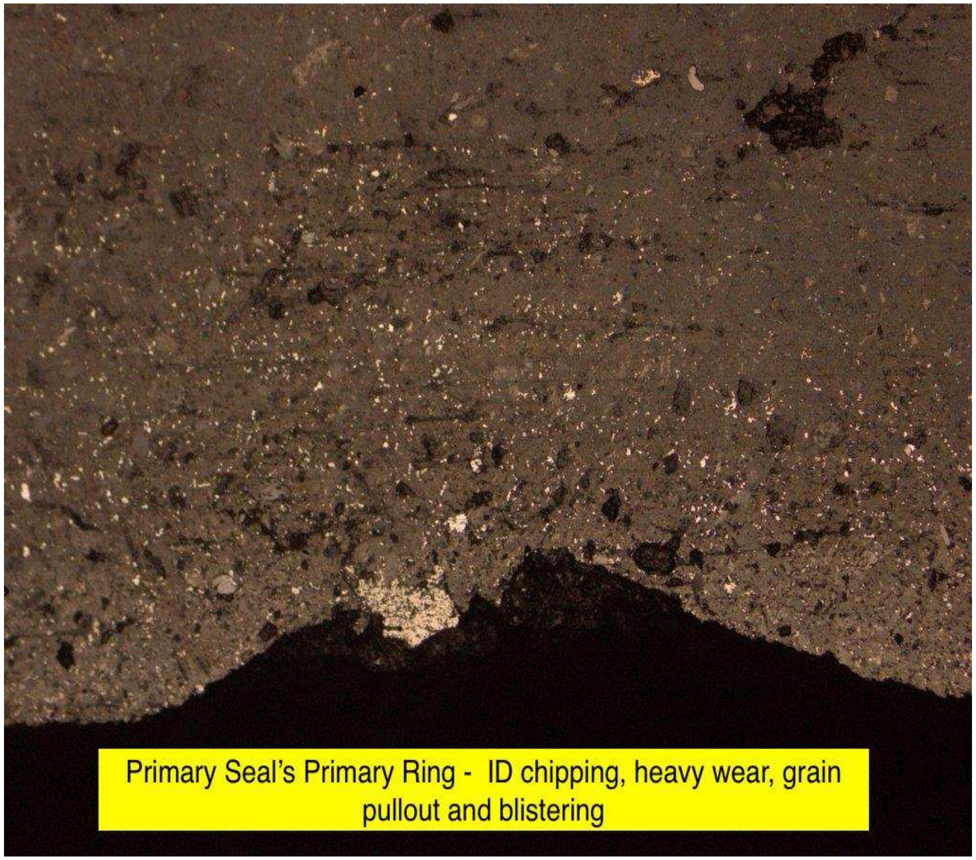

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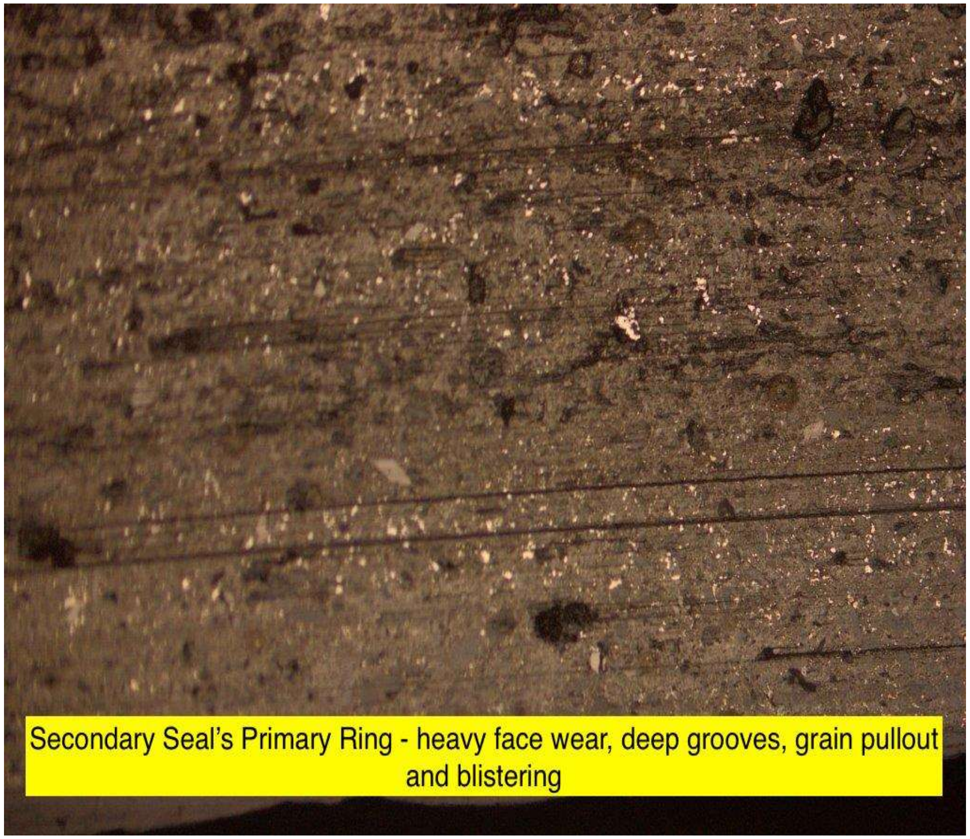

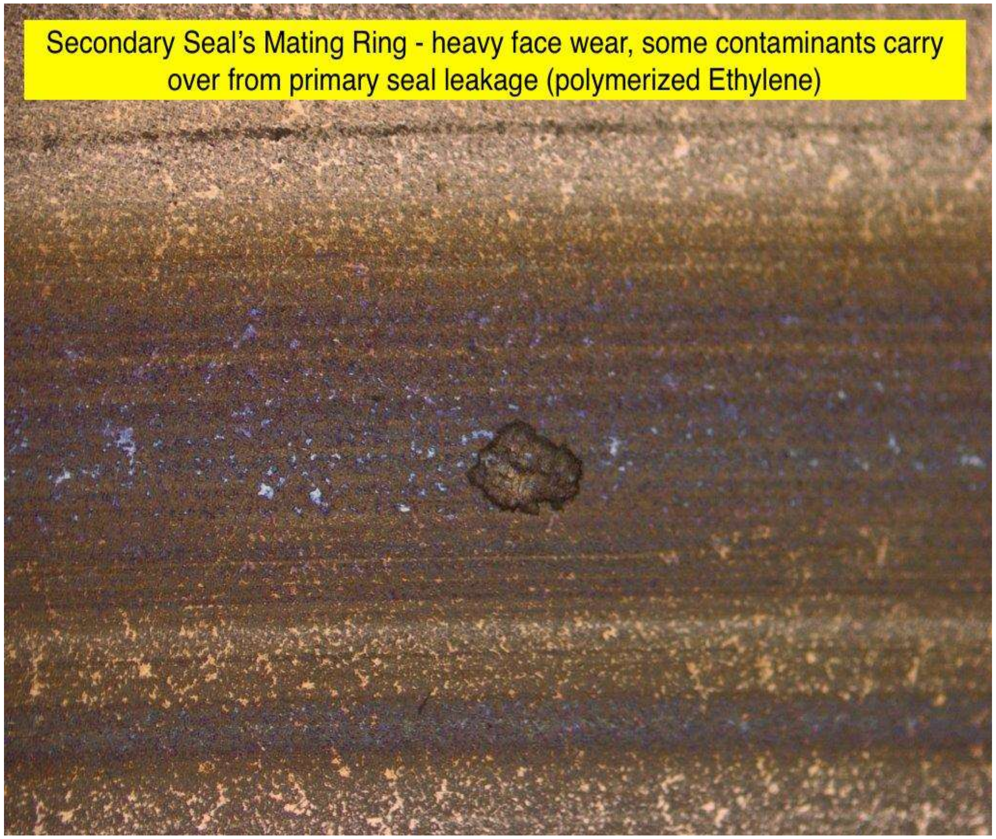

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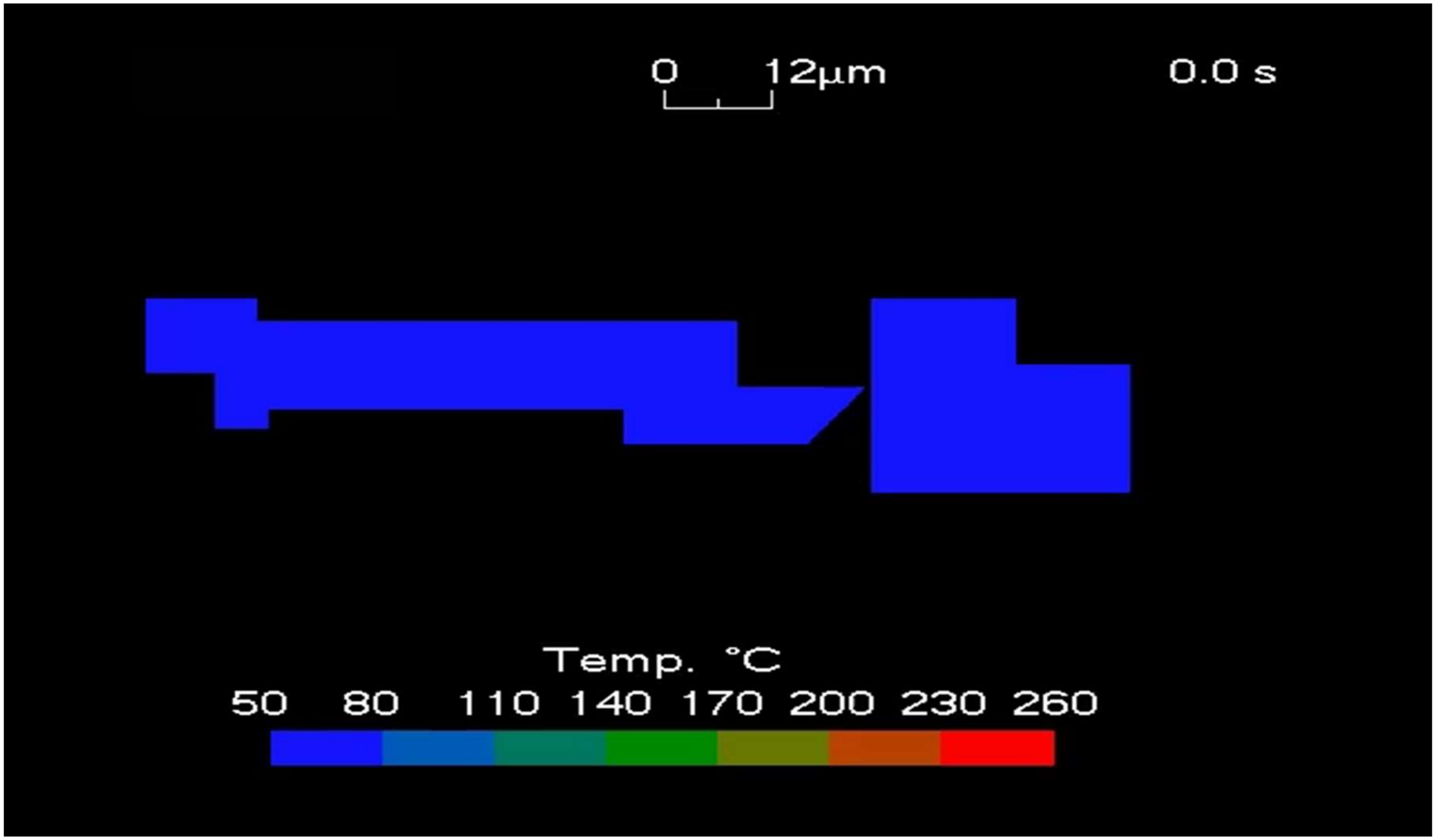
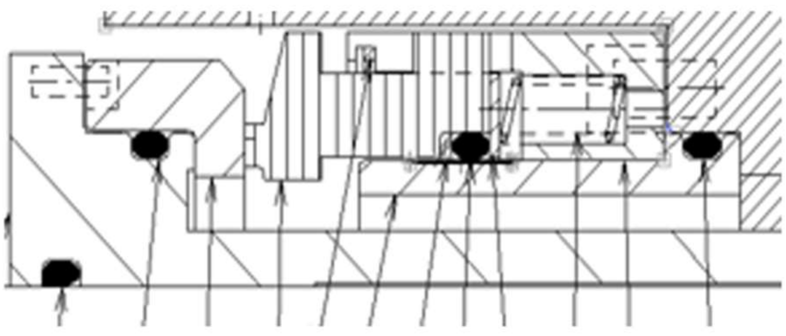
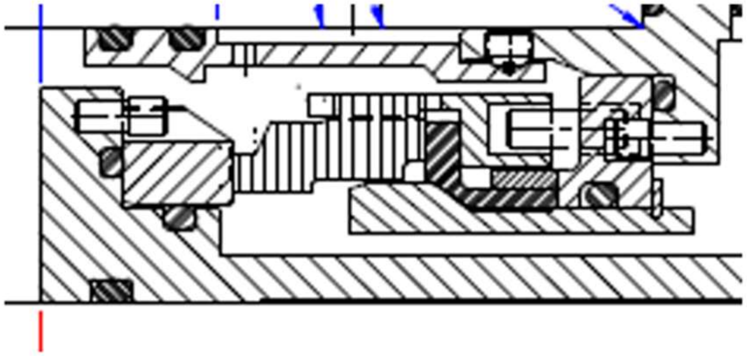


Inner Seal Comparison – Original vs Proposed:



Ø3.375" Pusher Seal - Original

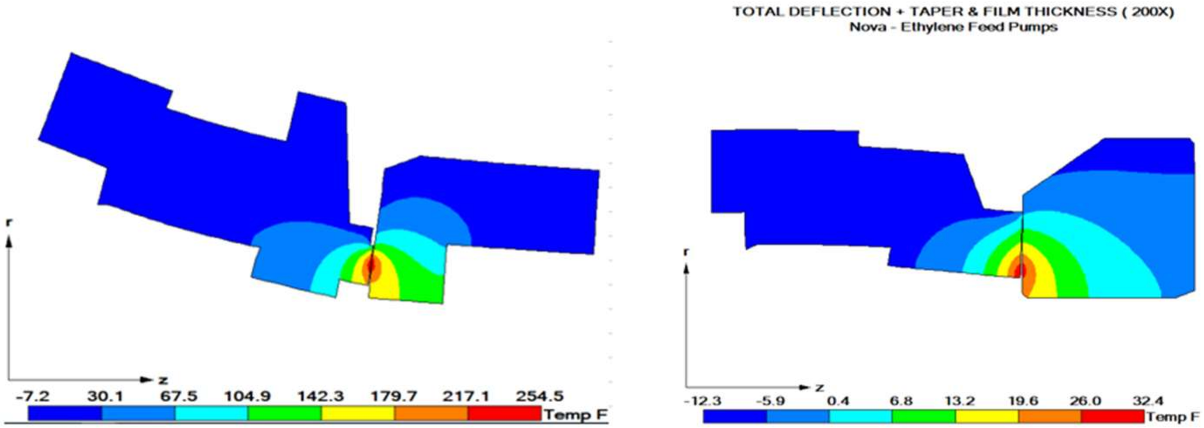
- Antimony carbon vs RB silicon carbide
- Dynamic o-ring
- Hydropads on carbon face



Ø3.500" Non-pusher seal - Proposed

- Antimony carbon vs RB silicon carbide
- 90 durometer NPSS
- Active Face Feature geometry etched on mating ring

FEA Comparison:

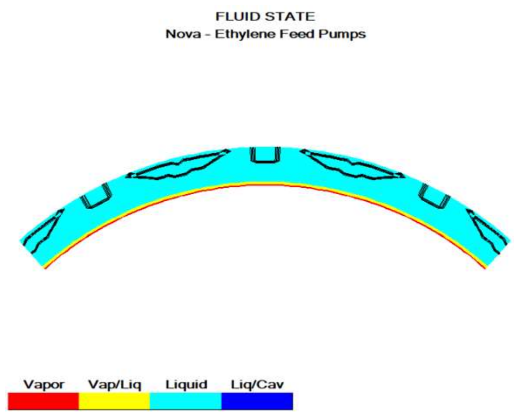


Original Inner Seal

Proposed Inner Seal

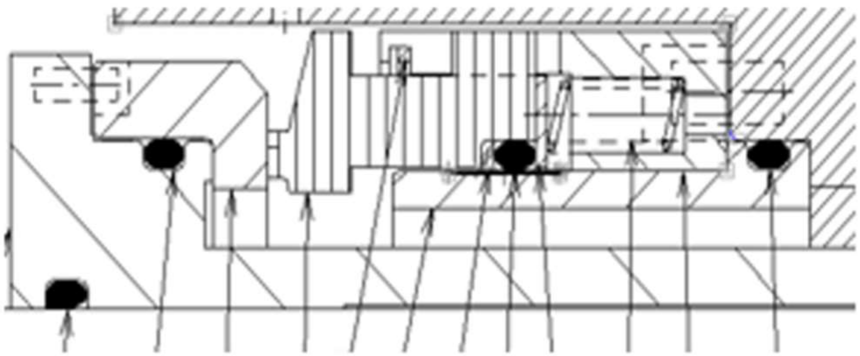
Percent Reduction with Proposed	
Heat Generation	74%
Contact Pressure	88%
PcV	88%
Pressure Rotations	77%
Avg Face Temp	85%

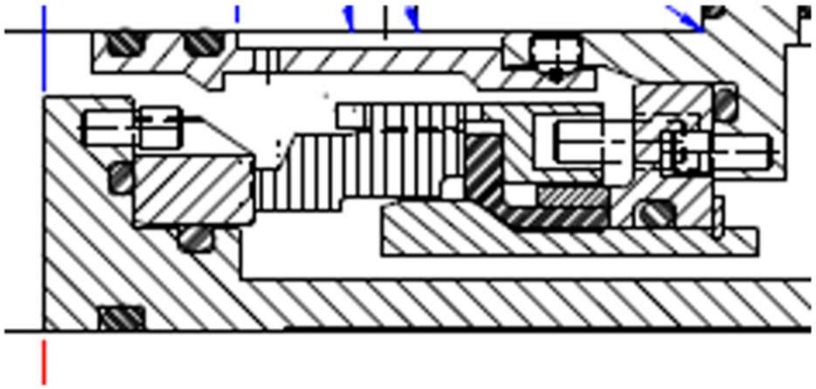
- Lower hydraulic balance with redesign
- Improved film thickness and face separation with face features to the mating ring.



CFD Analysis – API Plan 11 Flush Flow Guide:

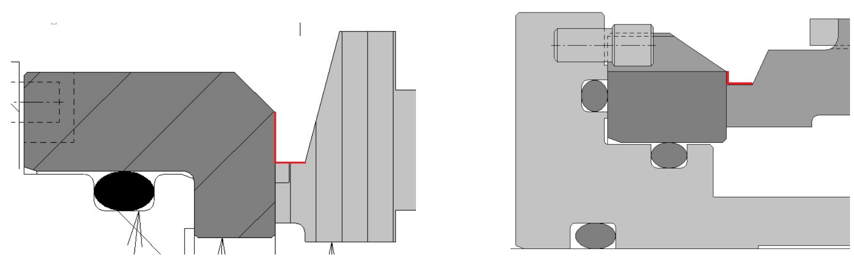
- A CFD analysis was performed to examine the Plan 11 and its effectiveness to remove seal face heat generated in both designs (original and proposed).



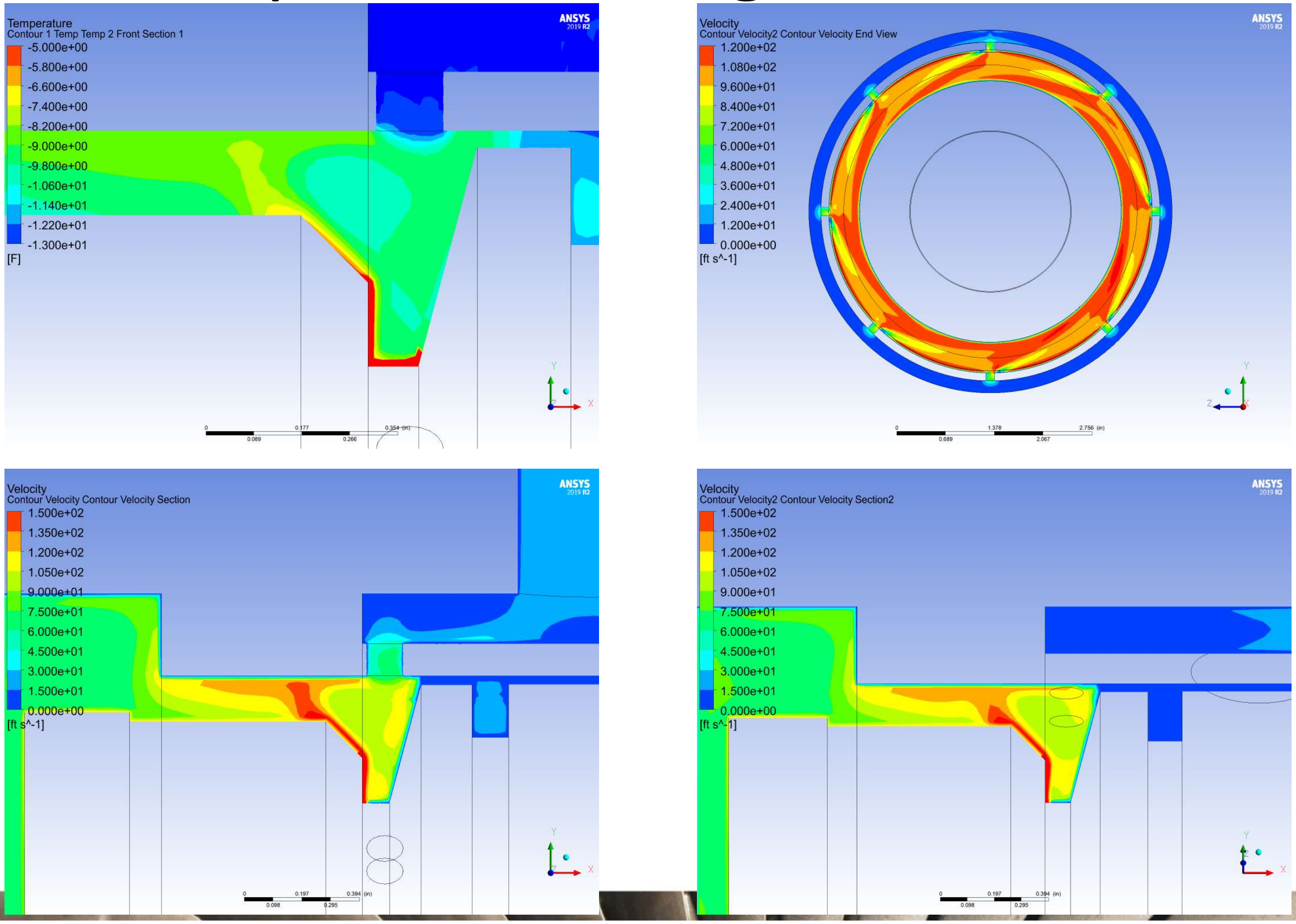


Boundary Conditions for CFD Analysis:

- Fluid properties based on ethylene at -25°C temperature.
- SG: 0.446
- Viscosity: 7.07E-5 Pa·s
- Specific Heat: 0.868 BTU/lb·°F
- Plan 11 flush from 1st stage discharge, 1223 psig (assumed 1/12th pump differential)
- Seal chamber outlet = suction pressure; 1102 psig
- Differential pressure across inlet and outlet: 121 psi
- Seal chamber throat bushing: 0.010” radial clearance
- Shaft Speed: 6200 RPM
- Heat input applied to the cylindrical primary ring nose and radial mating ring surfaces as a uniform heat flux



CFD Outputs – Existing:



Calculated Flow Rate:
16 GPM

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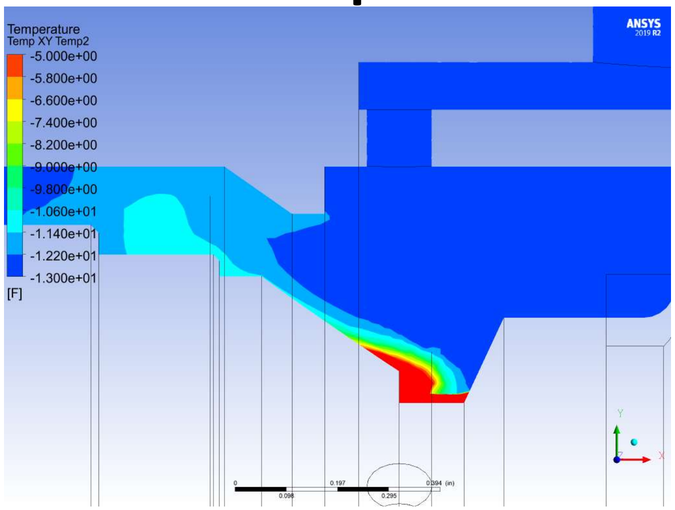
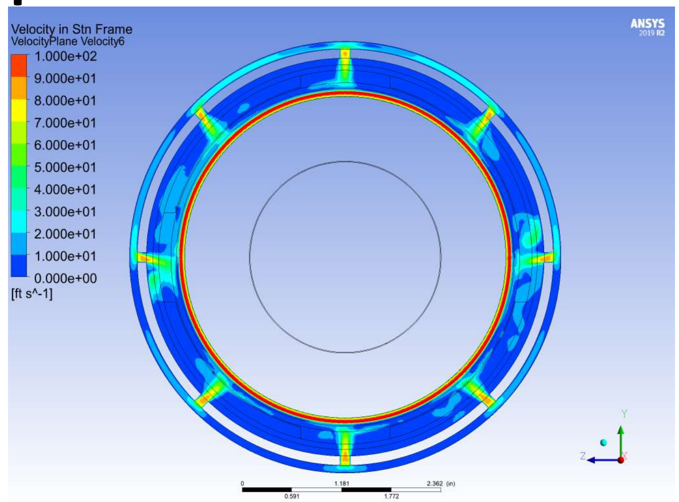
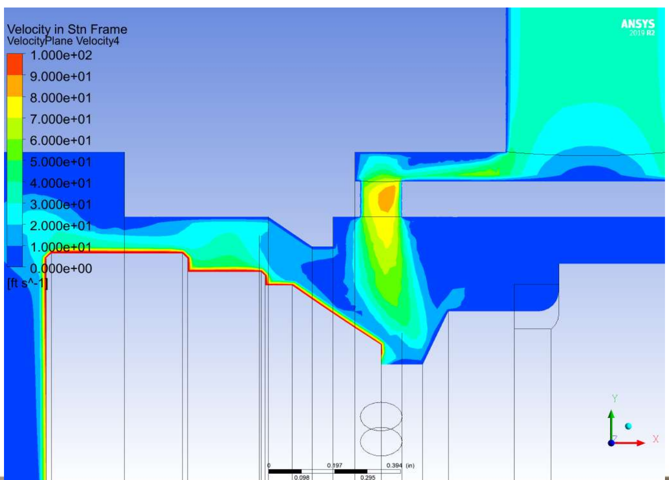
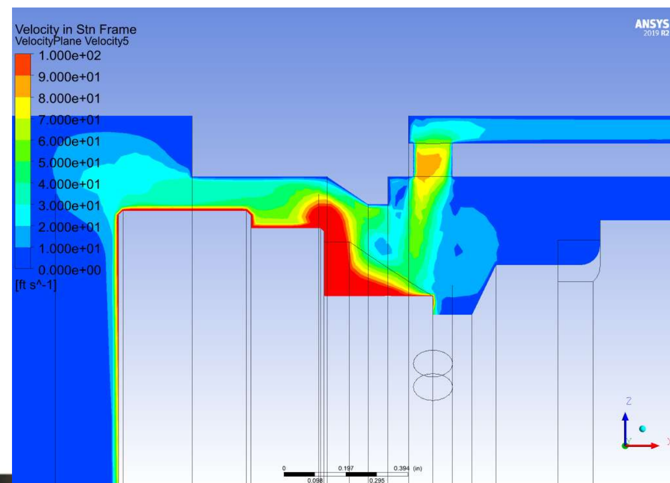
CFD Outputs – Proposed:





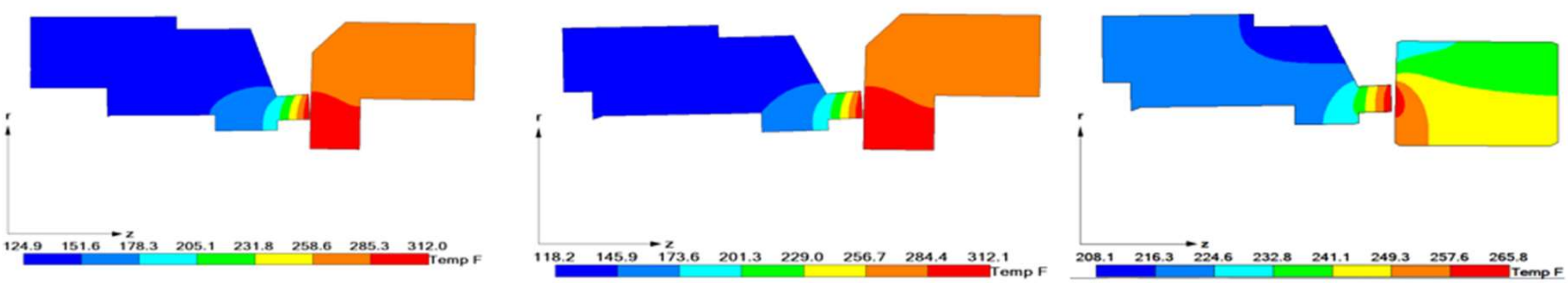




Calculated Flow Rate:
18 GPM

Containment Seal Modifications

Outer Seal	Original (Carbon vs SiC)		Option 1 (Carbon vs SiC)		Option 2 (SiC-G vs Diamond)	
	Startup	Steady-State	Startup	Steady-State	Startup	Steady-State
Heat Est (btu/hr)	2821	2918	3534	3631	4643	4661
Avg. Face Temp (F)	305	310	305	310	263.7	264
Taper Sum (min)	1.4	1.6	1.7	1.8	1.5	1.5
PcV (PSI-FPM)	42,858	0	0	0	5,776	0
Min Film (µin)	14.5	25.7	22.8	38.1	42	49
Contact Press (PSI)	9.0	0.0	0.0	0.0	1.0	0.0
Leakage (g/hr)	0.11	0.05	0.10	0.17	0.26	0.22



Original

Option 1

Option 2

Option 2 was selected for improvements in reduced interface temperature and reduction in PV. Leakage estimates were comparable to match performance of original containment seal.

API Plan 52 Support System Analysis

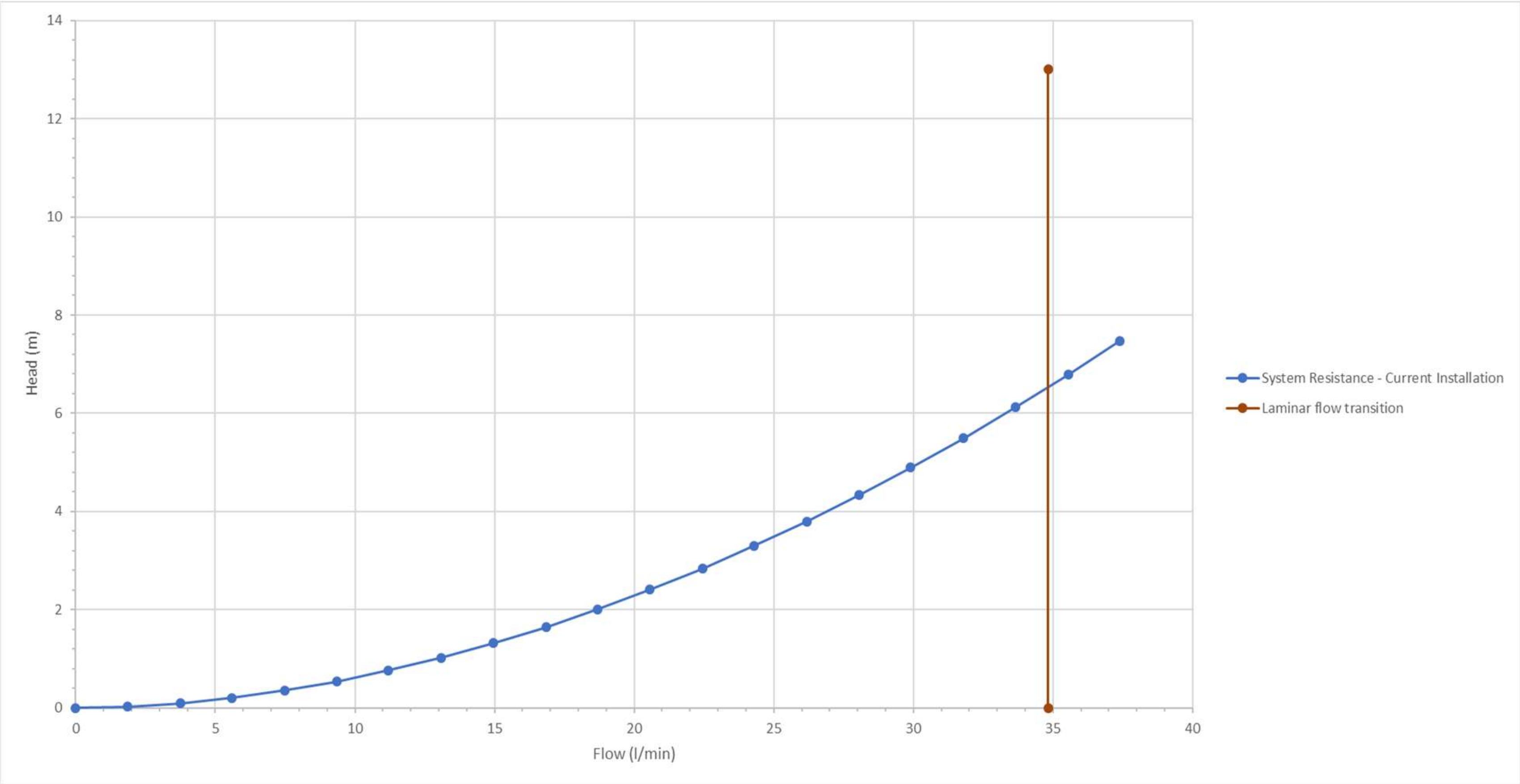
System Resistance Components:

- 4 x 90° Short radius bends
- 2 x Seal plate connections (reduction)
- 1 x Tangential seal plate hole
- 1 x Expansion connection
- 1 x Reduction connection
- 13.33 ft ¾" x 0.065" wall tube

Buffer Fluid

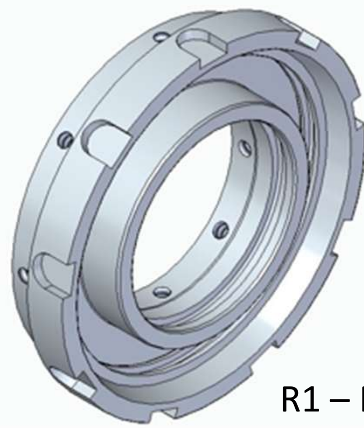
- Light Synthetic Oil
- Specific Gravity: 0.779 @ 50°C
- Viscosity: 4.8 cP @ 50°C

System Resistance Curve

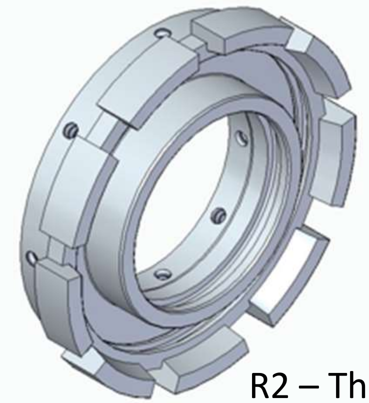


Pumping Ring Iterations for Analysis

Original

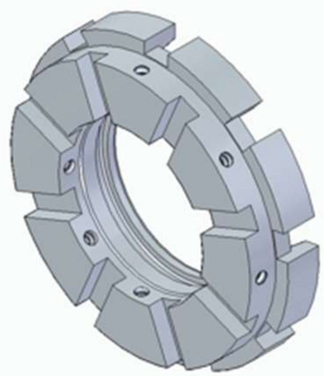


R1 – Milled Slots

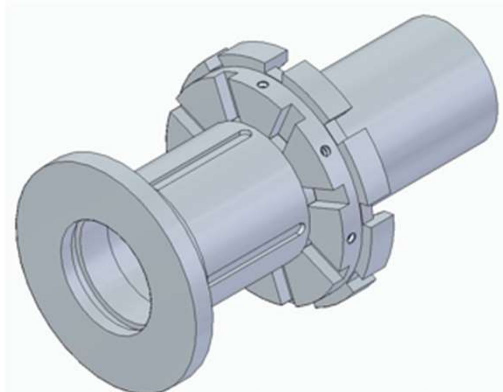


R2 – Through Slots

R3 – Radial Holes



R4 – Radial Slots

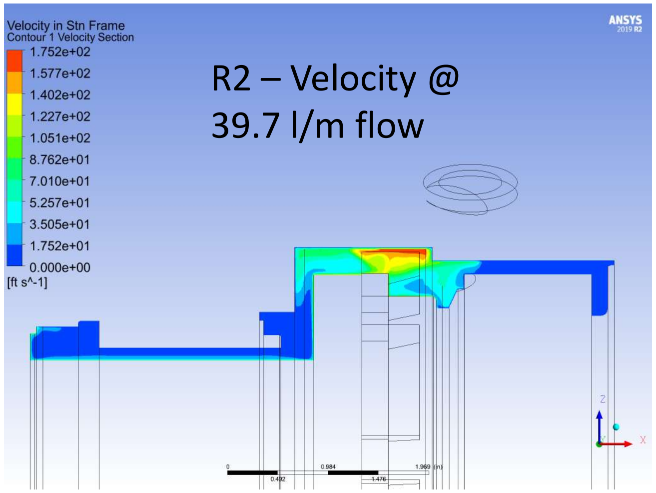


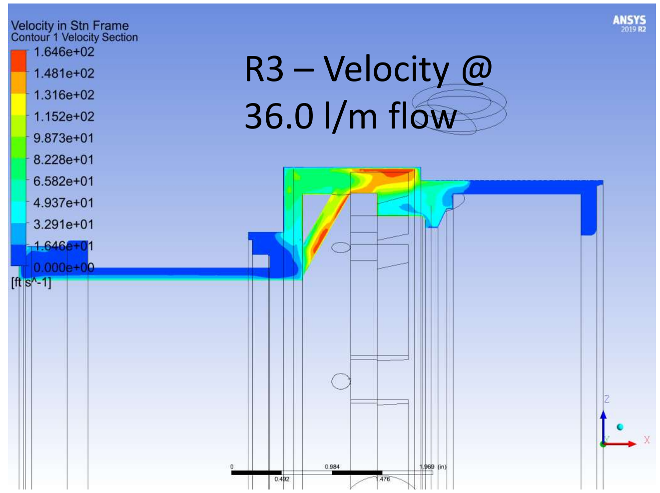
R5 – R4 w/ axial slots in sleeve

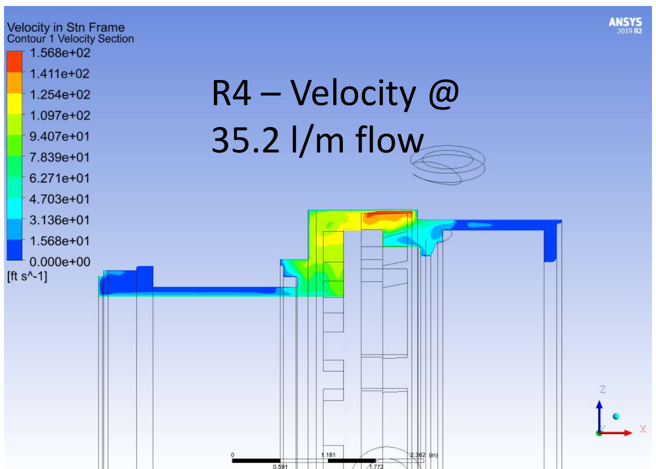
Pumping Ring Iteration Results

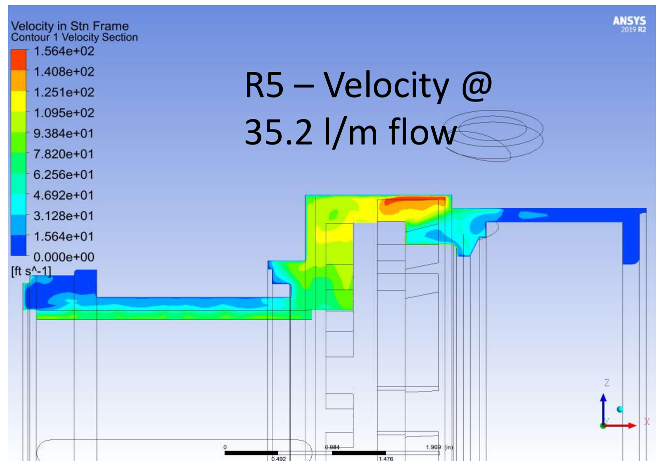
- Original pumping ring design yields results of 35.2 l/m (9.3 GPM) considering system resistance curve.
- R1 design of milled slots produced significantly lower flow rate when overlaid on the existing system resistance curve and was discounted.
- R2 design improved circulation rate slightly to 39.7 l/m (10.5 GPM); CFD predicted model shows room for improvement with fluid circulation throughout the containment cavity.
- R3 design iteration has comparable circulation rate to R2 at 36.0 l/m (9.5 GPM); addition of milled slots improves fluid circulation in adjacent containment cavity regions.
- R4 design iteration has comparable circulation rate to R3 at 35.2 l/m (9.3 GPM); CFD predicted model shows improvement of fluid circulation further into the containment cavity, beneath inner seal faces.
- R5 design iteration has comparable circulation rate to R4 at 35.2 l/m (9.3 GPM); CFD model predicts the best performance in terms of matching desired circulation rate with overall improvement to containment cavity circulation.

Pumping Ring Iterations – CFD Predictions









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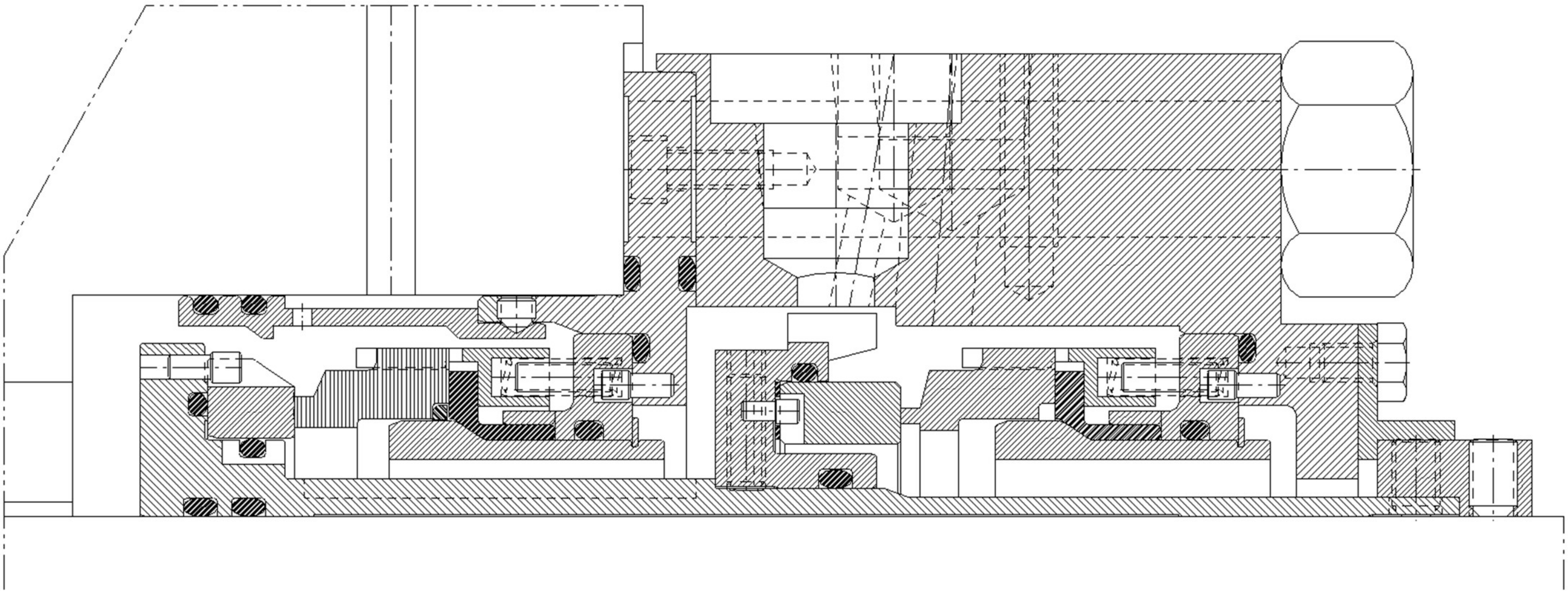
Finished Design:



Overall Results:

- Proposed mechanical seal was installed Sept 2021. To date:
  - Approx. 10 – 20 °C reduction in plan 52 oil temperatures observed on both DE and NDE seals.
  - Inner seal leakage results:
    - Measured by seal reservoir pressure transmitters
    - No change in performance observed during multiple pump stops/starts
    - Leakage rate is slightly higher than original seal as anticipated (hydraulic balance reduction and enhanced fluid film)
    - Leakage rate has decreased over time – seal profile wear in consistent with FEA results
- Pro-active mechanical seal inspection planned for fall 2023 to confirm modifications resulted in desired outcomes.

Thank you for your time!