Pharmaceutical Application Seal Problem

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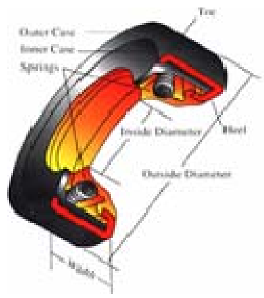


Recently we had a customer in the pharmaceutical industry that required a seal for a new application. The seal was being used in a plunger pump used to deliver carbon dioxide to a supercritical fluid reactor. The Supercritical Fluid Reaction (SFR) system was custom designed for the end user to rapidly react multiple compounds with supercritical CO2, and extract specific materials.

The nature of the process required the seals to be exposed to operating pressures of almost 960 bar at temperatures from +60F to +250C for this application. The seals were also routinely exposed to CO2 gas at various temperatures and pressures. In addition, the seal needed to function at design speeds of 250 feet/min. These elements combined to create an extremely challenging environment for the seal.

Specifically, the seal would be part of a high pressure CO2 piston pump system. The design requirements called for a pumping system that required low maintenance over a lengthy operating period. The seals would be operating in a non-lubricated environment within the piston compartment.

<u>Design</u>

After completing our initial design process review with the customer, our engineer recommended a carbon/graphite blended PTFE spring energized seal. The carbon/graphite blended PTFE provided for temperatures of up to 260C, and excellent wear resistance without lubrication on the reciprocating rod. Since this was a dynamic application, a stainless steel vee spring was added to the seal to ensure consistent lip interface at the recommended load. This unique profile also featured a backup ring to reduce the possibility of extrusion under extremely high pressures. The back up ring was machined out of Virgin PEEK. PEEK was chosen because of its high mechanical strength, stiffness and hardness. In addition, PEEK offered excellent wear and chemical resistance. Since this was a low volume part, it was manufactured using a programmable CNC lathe. There was no tooling charges, no minimum order quantity, and a quick turnaround time. A molded variant would have been suitable for higher quantity requirements.

Testing Results

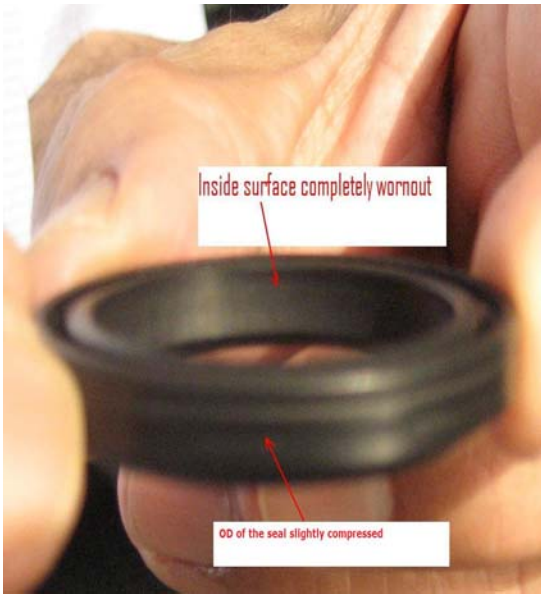
Within twelve days three first article samples of the recommended seal were produced and shipped to the customer. The customer tested the samples using operating conditions of 400 bar at 300 hours. After testing the following observations were made:

- excessive leakage on the ID of the seal
- lip ID was charred, cracked and excessively worn
- the seal OD was slightly compressed, but still intact
- visible cracks and wear were observed on the backup ring, and the backup ring broke apart upon disassembly
- seal extrusion had occurred through the cracks of the back-up ring

Failure Analysis

Acute visual analysis of the failed seals revealed a wear pattern that was circumferential in nature with slight blistering throughout the seal exterior. Excessive wear on the seal inner diameter was not uniform, and the heel of the seal was also deformed. Additionally, the edge of the heel, on the low pressure side appeared frayed and chipped. Other components of the extractor were also analyzed to determine if additional factors might have contributed to the seal failure. Shaft material and finish, housing bore condition, and the media were examined. For the purpose of this argument and for confidentiality reasons we cannot disclose the exact nature of the application, so we will only focus on the seal analysis and proposed solution.

Seal Lip Charring and Excessive Wear – This is an indication of heat degradation. Typical symptoms of heat degradation are a hard, brittle appearance of the seal. The seal may also show a breaking away of parts of the seal lip or body. Furthermore, the seal lip showed signs on being burnt as indicated by a deposit of a hard layer of carbon on a shaft seal's lip. The presence of carbon on the seal lip is a phenomenon called oil coking and comes about when the combination of high shaft speed and high temperatures create excessive under-lip temperatures. This increased temperature in turn burns and deposits the layer of carbon on the lip. This carbon crust blocks the pumping ability of the lip, making leakage inevitable. Another factor contributing to the effects of heat degradation is excessive lip loading. Lip interference is referred to as the difference between the diameter of a shaft seal's sealing lip and the diameter of the shaft to be sealed; interference is designed so that the lip diameter is smaller than the shaft diameter, thus ensuring the formation (and maintenance) of a contact point between the lip and the shaft. When excessive lip load is present it creates a situation where dynamic friction increases the underlip temperature.



Seal Extrusion – Increasing system pressures can sometimes forcibly push the heel of a seal into the gland's clearance gap. The extruded portion of the seal is susceptible to being chewed away to the point of failure. Increasing pressures can also expand metal components, often enlarging the clearance gap. Even if they don't increase under pressure, clearance gaps that are inherently too large or irregularly shaped are not desired. Obviously, the larger the gap, the easier it is for the seal to extrude. When the pressure returns to normal, depending on the seal material, the material memory may allow it to regain its original shape. Sometimes the seal will not completely evacuate the gap before pieces are torn off. Repeated instances of this nibbling can lead to seal failure. This type of extrusion is typical in dynamic rod and piston seals. Regardless of the application, excessive system pressure will increase the likelihood of seal extrusion.

<u>Solution</u>

When we looked at all the elements contributing to the seal's failure, the engineer decided to go with a completely different design. This new design, similar to a plunger packing assembly, will combine several elements to address the seal's performance criteria. First, to address the seal wear and charring on the inner diameter of the lip required addressing the seal's radial lip force and the primary sealing lip material. The radial lip force is the sum of all forces, such as seal interference and garter spring tension that maintain contact between a shaft seal's lip and the shaft. This measurement should be just enough to seal without generating unnecessary friction and seal wear. In this instance, the excessive friction and high pressures combined to create an environment with excessive lip loading. The lip load issue was corrected by slightly increasing the seal ID and removing the stainless steel spring. This reduced the lip load so when the seal was operating under pressure the additional pressure did not cause any excessive loading of the lip against the shaft there by reducing the under lip temperature. Also, since the seal was operating in a non lubricated environment our engineer opted for a composite, lubricated, fabric reinforced HNBR header ring. Changing the lip material from PTFE to HNBR reduced the excessive wear occurring on the lip.

The packing assembly also featured a pressure ring made of a blended PTFE. The pressure ring was used to provide the packing assembly with the required pressure and temperature resistance.

Plunger Packing Assembly

To address the extrusion issue our engineer slightly increased the outside dimension of the backup ring adaptor combination. Since cylinders tend to expand when pressurized, the size of the extrusion device was recalculated to more tightly fit a clearance between the piston and the expanded cylinder. A female adaptor was constructed out of a PEEK and Glass fiber blend with an additional metal anti-extrusion ring of Aluminum Bronze. These two elements combined to form and anti-extrusion device with a higher tensile modulus that provided maximum extrusion resistance given the operating pressures. To prevent the HNBR header ring from extruding through the top of the stuffing box, we also added an aluminum bronze spacing ring to the top of the packing.

Overall, this plunger packing combination offered our customer reduced seal lip wear and friction at high operating speeds. In addition all the elements combined to provide a seal with superior extrusion resistance, thereby increasing seal life. If you have any questions on selecting the right materials for your unique application contact Colonial Seal Co. at sales@colonialseal.com. You can also visit our website www.colonialseal.com for further information on other product lines.

References:

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Horve, Les. Shaft Seals for Dynamic Application. New York; CRC. 1996

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