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Beyond PFAS: Challenges and Opportunities in Material Innovation for replacing PTFE in Hydraulic Seals

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Abstract.

The European Chemicals Agency (ECHA) is currently evaluating a proposal to eliminate all nonessential uses of per- and polyfluoroalkyl substances (PFAS) as many of these substances are classified as potentially carcinogenic. A partial or complete ban on PFAS could severely impact many branches of industry as PFAS are widely used in a variety of applications. Nowadays, PFAS are also used in critical components of fluid power systems. One of the most important PFAS in fluid power applications is PTFE which is used e.g. in many piston and rod seals of hydraulic cylinders. The PFAS ban which is currently being discussed could also lead to severe restrictions on using PTFE seals in fluid power applications.

As a sealing material, PTFE combines many favorable properties, especially a very high temperature resistance, low stick-slip friction, low wear and excellent media compatibility. Therefore, a ban of PTFE seals would deprive hydraulics of one sealing material with a unique combination of properties.

In this paper, we present an overview of the challenges associated with replacing PTFE with an alternative material and discuss polyurethane as an alternative material for piston and rod seals in hydraulic cylinders. An evaluation of a PU and a PTFE piston seal shows that the investigated PU seals reached superior friction, leakage and endurance behavior for the investigated operating conditions, indicating that the selected polyurethane is a viable alternative even for hydraulics with high pressures and high temperatures.

Keywords. Hydraulics, PFAS, Piston Seal, Polyurethan, PTFE, Tribology.

1. INTRODUCTION

Since 2023, the proposal by the European Union and other international authorities to regulate PFAS chemicals has been causing discussions about the impact of upcoming regulations in almost all industrial sectors. PFAS are part of many industrial and everyday products like frying pans and raincoats. For fluid power PFAS can occur among others in lubricants, hydraulic oils and seals. Seals are functionally critical and often life time determining components of all fluid power systems. Therefore, this paper focuses on alternatives to PFAS materials on hydraulics seals. The scope of this paper is the evaluation of an alternative material to PTFE as one highly performant sealing material.

This paper starts with a brief overview of the current status of the regulations. After that, the unique properties of PTFE are outlined and discussed with respect to the demand of hydraulic seals. After that, polyurethane (PU) is proposed and investigated as an alternative material for hydraulic applications. The performance of different PU materials regarding temperature and media resistance for hydraulic applications is compared to select one especially suitable material for experimental comparison to PTFE in terms of friction, leakage and endurance.

2. PFAS IN THE CONTEXT OF FLUID POWER SEALS

In this chapter, a brief overview of the timeline of the PFAS regulation in the EU will be given. Afterwards, the possibly affected substances in hydraulic sealing systems and their unique properties will be briefly highlighted. Focusing on PTFE, as an exemplary component and material, typical hydraulic seals within a cylinder are discussed with respect to the required material properties.

2.1. Regulatory Background

The European Chemicals (ECHA) has proposed a regulation for the substance class of per- and polyfluoroalkyl substances (PFAS). PFAS denote “any substance that contains at least one fully fluorinated methyl (CF3-) or methylene (-CF2-) carbon atom (without any H/Cl/Br/I attached to it)” [1]. Since then, an updated restriction proposal has been published [2], in which sealing applications are named as an evaluated sector. Outside the EU, different PFAS regulations are also in discussion or under effect, e.g. in Japan, China, Canada and different states of the USA – the timeline and affected substances differ from region to region. The timeline of the PFAS regulations in the EU is shown in Figure 2.1.

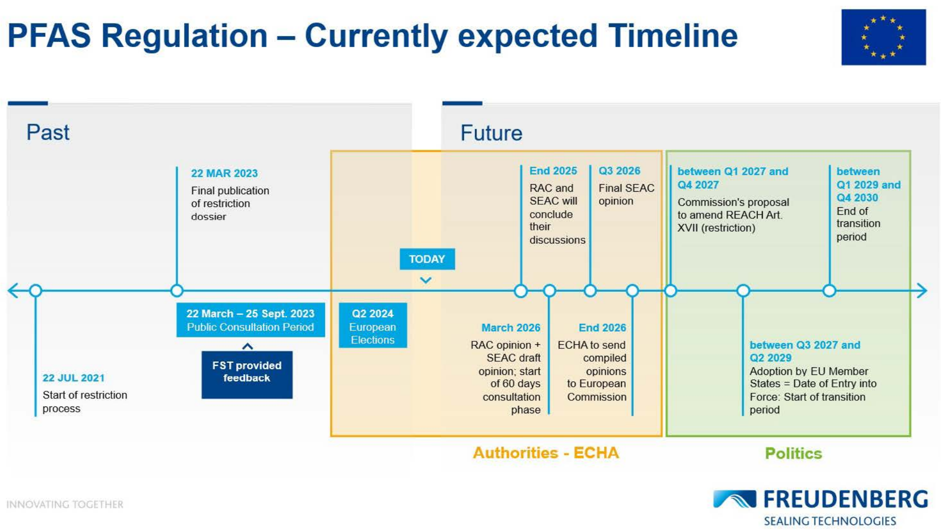

Figure 2.1. Expected Timeline for PFAS regulations [3] as of end of 2025.

As shown in the timeline above, the restriction process takes several years to go from initial proposal until it takes effect. This is partially due to the high number and huge diversity of different existing substances. The OECD discussed and propose different categories to distinguish between different groups of PFAS [4]. A discussion of different grouping strategy is discussed by Cousins et al [5]. They compare several approaches for grouping PFAS and evaluating the effects and adequate measures for restriction of these groups. The discussed grouping strategies range from a general approach covering all PFAS up to approaches differentiating between intrinsic properties such as mobility in water or approaches based on risk assessment such as toxicity.

One common differentiation that is often used in the public discussion between manufacturers and customers is the classification of PFAS based on polymeric and non-polymeric PFAS. For most sealing applications, polymeric PFAS are covering the most important materials such as plastics like PTFE, PVDF, PFA, rubbers like FKM, FFKM, FVMQ and base oils like PFPE. The category of non-polymeric PFAS covers substances with small molecules such as gases for refrigerants, foaming agents and liquids like fire fighting foams or coatings in textiles. The most important non-polymeric PFAS for sealing applications are fluorinated surfactants used as process aids in the manufacturing of polymeric PFAS like FKM. In case of a differentiation between polymeric and non-polymeric PFAS, where only non-polymeric PFAS would be affected, it is possible to adapt the manufacturing processes in order to evade the usage of these non-polymeric PFAS. This transitioning is already being made by suppliers of FKM materials.

2.2. Use of PFAS in Sealing Systems

In fluid power sealing systems, the most important substances are the fluorinated elastomers FKM and FFKM, the fluorinated silicones FVMQ as well as Polytetrafluoroethylene (PTFE). Their unique combination of high temperature stability media resistance and low friction and wear makes them an attractive material for a variety of applications ranging from transportation, food & beverage to fuel cells or batteries [6]. The material compatibility of materials and fluids is typically evaluated using insertion tests as shown for hydraulic fluids and bio-hybrid fuels e.g. in [7] and [8]. A comparison of the temperature stability and swelling behavior is given in Figure 2.2.

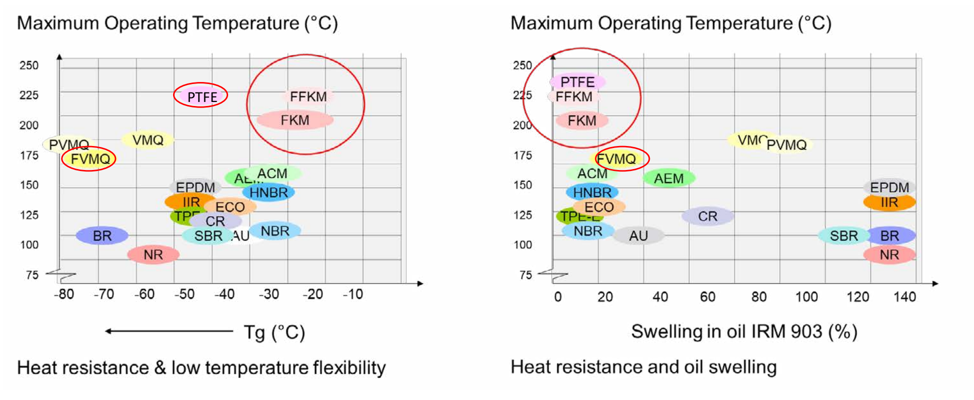

Figure 2.2. Classification of elastomer materials according to ASTM D2000 / SAE J200 PFAS substances are highlighted [6].

As seen in Figure 2.2, simply replacing all PFAS containing materials with other currently available materials would cause a loss in functionally relevant properties potentially leading to shorter maintenance intervals, premature failure of sealing systems as well as leakage of potentially hazardous fluids into the environment. Especially in the aerospace and chemical industry e.g. for processing aggressive chemicals or in the pharmaceutical and medical industry where in dosing applications the seals have to withstand both the medications and the fluids and conditions used in the cleaning and sterilization cycles. In addition, seals in medical applications have to undergo an extensive certification according to international standards such as EN ISO 10993-5:2009. [6]

The beneficial properties of PFAS containing materials for sealing applications can be summarized as follows: [6]

- High wear resistance
- Low friction coefficient
- High temperature stability
- High media resistance
- Low swelling in contact with fluids
- Permeation tightness for gases
- Compliance with industrial standards for medical safety

2.3. Typical Fluid Power Seals

In typical fluid power applications, several seals can currently contain PFAS materials. These include both rod and piston sealing package in hydraulic cylinders (wipers, rod seals, guide rings, buffer seals, piston seals), see Figure 2.3, as well as static seals and rotating seals (e.g. swivel seals and rotary shaft seals). For pneumatic applications, similarly both static and dynamic seals can be affected by possible regulations.

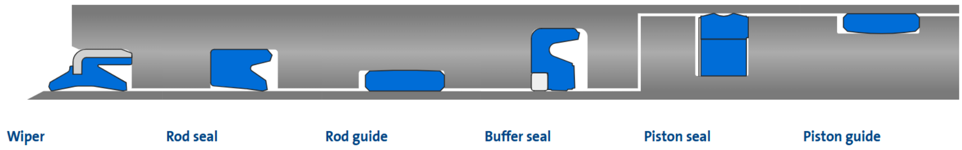

Figure 2.3. Typical sealing system of a hydraulic cylinder.

The main materials include FKM and FFKM, e.g. for static seals and preloading element in two-piece hydraulic seals, and PTFE mainly used in profile rings for profile rings in two-piece hydraulic seals. For illustration purposes, some typical designs[1] of hydraulic rod seals are shown in Figure 2.4. The first seal consists of just one piece which gets deformed when exposed to a pressure difference so that the contact pressure increases at higher operating pressures. The preloading of the seal results from the interference of the flexible seal with housing and rod. The second seal consists of two parts: a profile ring which has a similar function as the aforementioned one-piece seal and the back-up ring which reinforces the seal against gap extrusion. The third design shown also consists of two parts. However, here the profile ring gets reinforced by a preloading element (such as an O-Ring or a metal spring).

The first and second of the shown designs typically use polyurethane for the profile ring because of the required flexibility to preload the sealing contact. The back-up ring typically consists of a thermoplastic polymer. Thus, the first and second kind of seals do usually not contain PFAS materials. For the third option shown, PU, PTFE or thermoplastic polymers such as PA can be used for the profile ring. The preloading element typically consists of an elastomer part made from NBR or FKM or a metal spring. In conclusion, mainly the third kind of rod seals could be affected by PFAS regulations, as here both profile ring and preloading element can contain PFAS material if they are made from PTFE or FKM, respectively. Due to the lack of flexibility of PTFE, it is not used in seal designs where flexibility of the profile ring is required.

[1] These three designs are the most typical designs to occur in hydraulic applications with average diameters and operating conditions. For special applications e.g. special media, high temperatures, large diameters or special requirements, other seals like PTFE V-packings are also used but will not be covered in this paper.

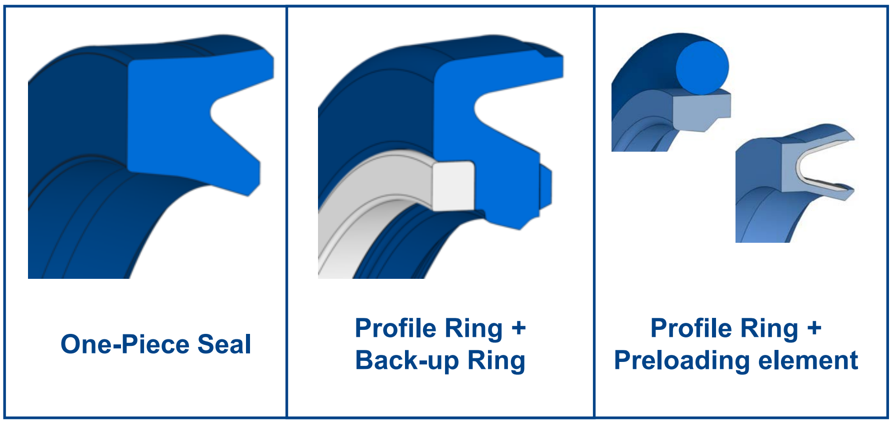

Figure 2.4. Different Seal Designs for Rod Seals.

Although slightly different in shape, similar designs to the ones shown in Figure 2.4 are also used for piston seals. For wipers, PU and elastomers like NBR and FKM are the most common material, however two-piece versions with PTFE and an elastomeric preloading element are also used. For guide rings, either PTFE or fabric-based laminate e.g. consisting of cotton-based fabric and a phenolic resin is used.

2.4. Material Requirements of Fluid Power Seals

When comparing the abovementioned strengths of PFAS containing materials with typical demands of fluid power applications (hydraulics and pneumatics) it becomes evident that not all of the properties are equally relevant for hydraulic applications. Whilst high wear resistance and low friction are still desirable properties of a seal in a hydraulic system, the importance of the other benefits is typically lower than in the previously mentioned highly demanding applications:

The temperature range in a hydraulic system is considerably lower, also because other components limit the ideal operating conditions (e.g. the degradation of mineral oils due to high temperatures as well as the temperature stability of the hoses and accumulators). Thus, the recommended maximum system temperature of a typical hydraulic system is less than 80°C [9], whereas typical stationary temperatures for mobile and industrial hydraulic applications range at around 40 to 60°C [10]. For aerospace applications, the occurring temperatures may vary.

The media resistance and low swelling has to be considered when choosing seals in fluid power applications. Similar to hydraulic systems, in pneumatic systems the seal only gets in touch with the lubricating grease[2]. For pneumatic systems, a good compatibility with the grease is important. In hydraulic systems the only media in contact with the seals is the hydraulic fluid itself (potentially containing entrained air and water). Due to the high effort

[2] Some greases in pneumatic applications contain PFAS themselves. For designing a sealing system without PFAS containing materials, the interaction of grease and sealing material has to be carefully considered. Due to the scope of this paper, only PFAS in the sealing material itself are taken into account here.

of changing the oil type of a complete hydraulic system, a hydraulic system mostly sticks to one type of oil. This means that far less media get in contact with hydraulic seals during their lifetime than seals in other applications e.g. in chemistry. However, the compatibility of sealing material and fluid is still crucial and cannot necessarily be taken for granted for all combinations of hydraulic fluids and sealing materials. Experimental results for the media compatibility of selected materials are shown in chapter 3.

The permeation tightness for gases is not important in typical fluid power applications. The compliance with medical safety is not important for most hydraulic systems. For pneumatic systems, the importance of compliance heavily depends on the application.

3. POLYURETHANE AS AN ALTERNATIVE FOR HYDRAULIC SEALS

In this chapter, the basic differences between PTFE and PU are compared from a material point of view. As a first step, the general material properties are compared and evaluated regarding their implications with respect to hydraulic applications. In the next step, the resistance to hydraulic fluids, one functionally critical property of hydraulic seals, is evaluated for six different polyurethanes.

3.1. Comparison of Material Properties for Hydraulic Seals

Besides the aforementioned favorable temperature and media resistance, PTFE also brings some unique properties that have to be paid attention to when designing hydraulic seals. First, in comparison with elastomers or PU, PTFE is not an elastic material and tends to deform plastically rather easily. The lack of elasticity means that PTFE seals typically use simpler geometries than PU seals because complex geometries are more difficult to manufacture with PTFE and also tend to get “simplified” due to plastic deformation in the application. The potential benefit of complex geometries is shown in the experimental data presented in chapter 4.

One additional consequence of the plasticity and softness of PTFE is that it is rather prone to getting damaged during assembly such as due to chamfers, threads and improper handling. Additionally, for the assembly in tight spaces, PTFE often needs to be pre-heated to around 80°C and adjusted in diameter (i.e. widened for piston seals and made smaller for rod seals). After assembly, the diameter of the seal has to be re-calibrated by plastically deforming the seal with a cone. In comparison, the assembly of elastic materials is generally easier and less prone to damaging the seals.

Disadvantages of PU in comparison to PTFE are a higher friction coefficient (especially relevant for breakaway friction) and a smaller tolerance towards the immersion in different fluids at high temperatures. In the next section, the material compatibility of different PUs with typical hydraulic fluids will be investigated.

3.2. Changes of Tensile Strength of Different Polyurethanes in Hydraulic Fluids

The material compatiblity is shown in the Figure 3.1, Figure 3.2 and Figure 3.3 for six different polyurethanes all of which are used in hydraulic sealing applications. The loss of tensile strength is chosen as one representative material property that can changes during exposure to fluids at high temperatures. As reference fluids three commercially available hydraulic oils were chosen. The first of which is a mineral oil (HVLP), the second a fire-resistant water-glycol solution (HFC) and the third a synthetic esther based (HEES). The temperatures were chosen according to typically allowed maximum operating temperatures for polyurethanes. For assessing the material compatibility, the polyurethanes were exposed to the respective fluid and temperature for the indicated number of weeks. After the storage, the tensile strength was determined and compared to the value of a non-exposed specimen.

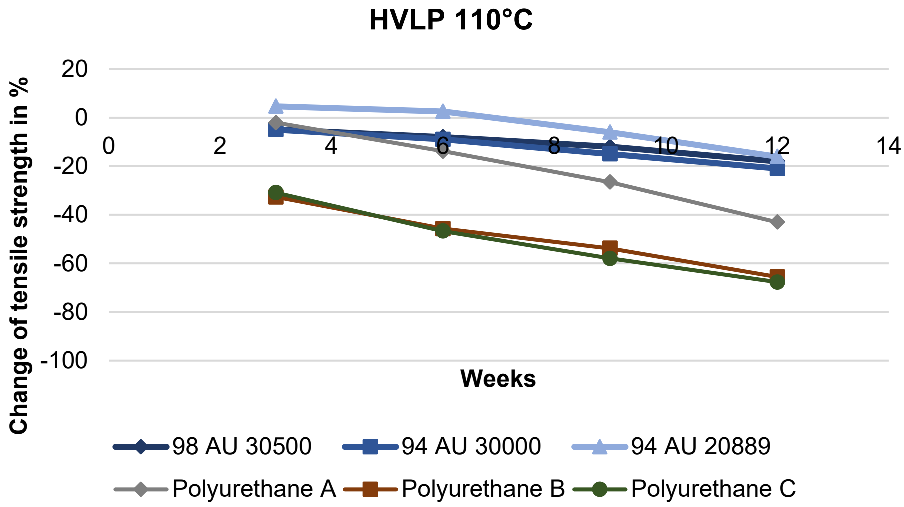

Figure 3.1. Change of tensile strengths for different polyurethanes in HLVP at 110°C.

It can be seen that the loss of tensile strength depends heavily on the chosen fluid and temperature. In other experiments (not displayed here) it could be shown that the exposure at lower temperatures generally had lower effects on the change of tensile strength. Most of the materials lose tensile strength during exposure to the fluids and temperatures. A too high loss of tensile strength can indicate that the material might perform worse in the practical application. In the worst case, the material can become so brittle that the seal specimens break by slight loads applied with bare hands.

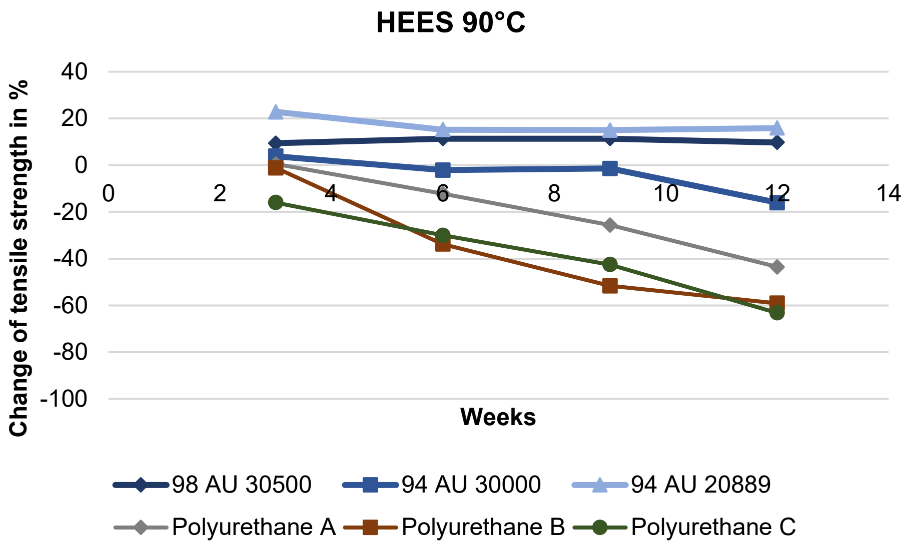

Figure 3.2. Change of tensile strengths for different polyurethanes in HEES at 90°C.

Even though the behavior when exposed to different fluids varies for each combination of fluid and material, it becomes evident that three of the investigated materials (98AU30500, 94AU30000 and 94AU20889) show particularly low changes of tensile strength for all three liquids.

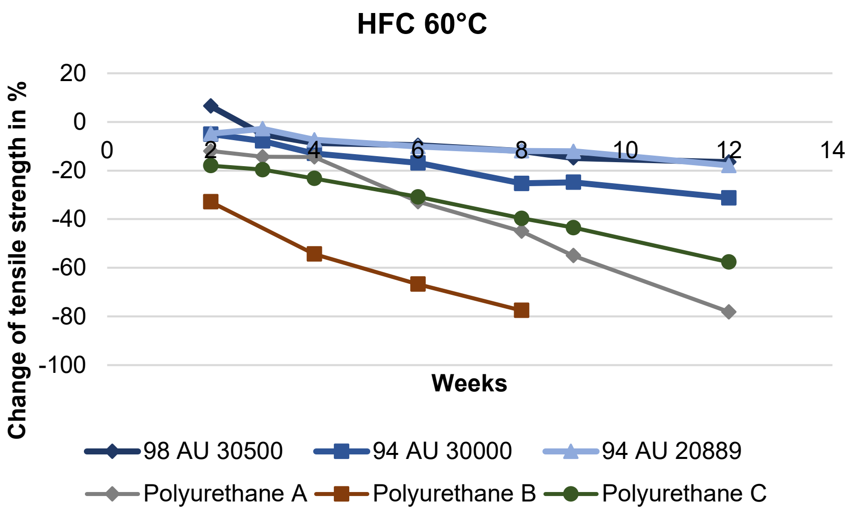

Figure 3.3. Change of tensile strengths for different polyurethanes in HFC at 60°C.

Concluding the immersion tests, it was shown that some combinations of fluids and high temperatures can cause huge changes in the material properties of polymers. However, despite the large differences between the chemical structure of the three investigated fluids, some polyurethanes performed especially well by showing lower changes in tensile strength than the other investigated materials. This indicates that there are chemically resistant polyurethanes that can indeed be used in a variety of hydraulic applications with long-term exposure to different media at high temperatures.

4. Experimental Results

In this chapter, the performance of PU seals is assessed in comparison to PTFE seals using experimental investigations on a hydraulic test rig. For the scope of this paper, piston seals are chosen as the reference. In the first section, the test rig is introduced briefly. In the following sections, friction, leakage and lifetime are assessed. Goal of the investigations is to show how PU seals compare with commercially available PTFE solutions.

4.1. Hydraulic Piston Seal Test Rig

For the investigations presented in this chapter, a hydraulic piston test rig was used. The test rig uses five separate modules. Each module consists of a piston, a hollow rod and a tube. Each module tests up to three seals at the same time, all of which are mounted on the piston as shown in Figure 4.1. During operation, a linear drive moves the piston back and forth within the tube. The two chambers between seals 1/2 and 2/3 are pressurized individually through channels in the hollow rod. Pressurization is chosen in accordance with the movement to imitate the operating conditions occurring in a differential cylinder for the middle seal 2.

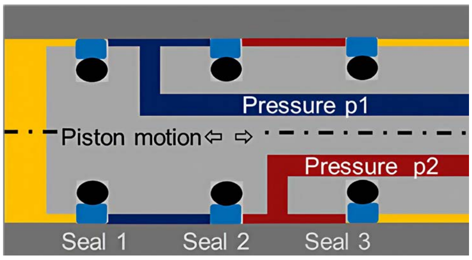

Figure 4.1. Schematic of one Module of the Piston Seal Test Rig.

A force sensor measures the friction force of the piston in parallel. The leakage of the outer seals 1 and 3 is assessed by gathering the droplets at both ends of the tube. The reciprocating motion of the piston is repeated until the chosen number of cycles is reached or when any of the seals is damaged in such a way that the chambers between the seals cannot be pressurized anymore.

4.2. Comparison of Measured Friction Forces

To compare the friction force of a PU and a PTFE piston seal, these seals were installed on the test rig described in section 4.1. Both seals are commercially available as double acting piston seals. The PU seal is a Simko 300 and is made of 98 AU 928. The geometry was optimized to gain a good combination of low leakage and low friction force. As investigated parameters, a velocity of 0.3 m/s and an oil temperature of 60 °C were chosen. The friction forces were evaluated at 50, 100, 200, 300 and 400 bar. The measured average friction forces of the two seals are shown in Figure 4.2, all normalized to the same reference force F_{Ref}. It should be taken into consideration that the test rig measures the friction force of one module with three seals at once as shown in Figure 4.1.

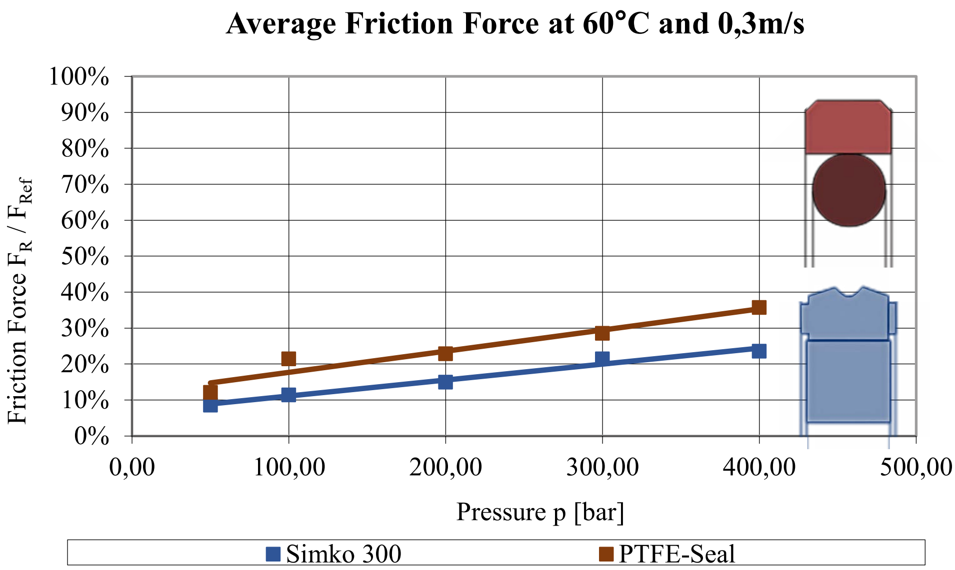

Figure 4.2. Comparison of the Friction Forces between a PTFE and a PU seal for Different Operating Pressures.

When evaluating the results, it should be noted that the friction forces during operation vary with different oils, temperatures, pressures and kinematics. However, the comparison of the two seals shows that the friction force of the PU seal at these operating conditions is lower for all investigated pressures between 50 and 400 bar. This indicates that although the friction coefficient for PTFE/steel is typically lower than for PU/steel, this does not necessarily cause higher friction forces for PU seals than for PTFE seals. The better performance of the PU seal can be attributed to the more favorable geometry of the PU seal, which has been designed to reach optimal hydrodynamic lubrication between seal and countersurface to deliver a good balance between low friction and low leakage. The geometry used for the PU seal is typically not feasible for PTFE seals due to difficulties in manufacturing and plasticity of the sealing material, which is why PTFE seals often use more simple geometries than PU seals.

4.3. Comparison of Leakage Measurements

The leakage of the two seals investigated in the previous section, the same test as shown before have been used. The seals designs are the same as in the previous section. The leakage has been determined after the test.by measuring the amount of leakage from seals 1 and 3 as shown in Figure 4.1. It should be noted that the leakage of seal 2 cannot be detected with the used test rig. The results of the leakage measurement are shown in Figure 4.3. The values for both seals were determined in the same operating conditions on the same surfaces and are given in the unit ml per 1000 doubles strokes (DS).

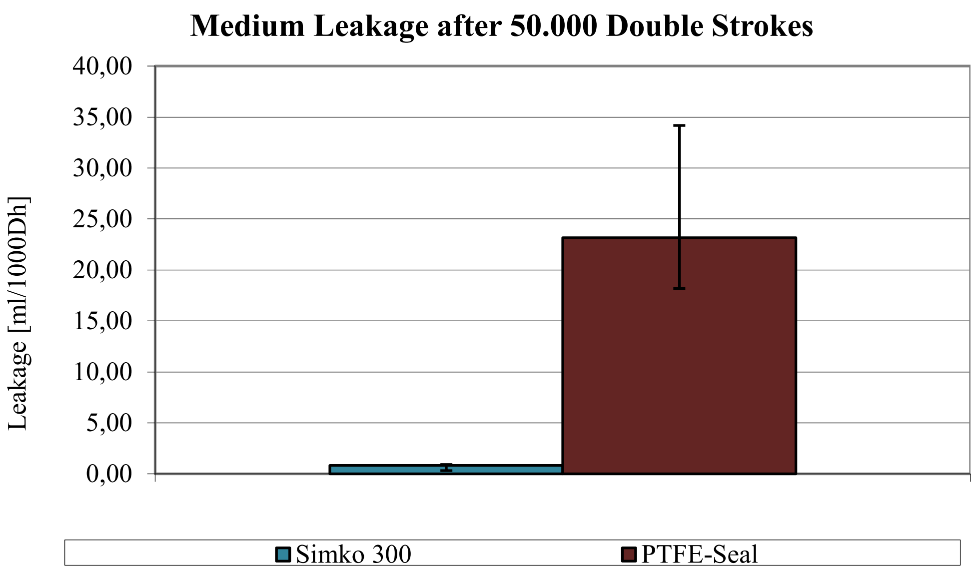

Figure 4.3. Comparison of the leakage of a PTFE and a PU seal.

The comparison of the measured leakage shows that the PTFE seal shows about 20 times higher leakage than the PU seal. This is especially remarkable considering that the friction force of the PTFE seal was higher than the friction force of the PU seal, indicating that the chosen geometry of the PU seal caused more favorable hydrodynamics than the geometry of the PTFE seal.

4.4. Endurance Test

Finally, after evaluating friction and leakage, the endurance of PU seals will be evaluated. Even more than friction and leakage, the lifetime of a seal is highly depending on the interaction of various operating conditions. The same seal design and material can reach the end of its life time in many different ways depending on the operating conditions. Some common failure modes are excessive abrasive wear, chemical deterioration of the material and gap extrusion. The latter mechanism will be the dominating failure mechanism for the operating conditions chosen for the investigation in this paper. Note that the seals and materials tested here are from the ones shown in the previous two sections.

For quickly evaluating the durability of piston seals, the formerly introduced test rig is used. As operating conditions, the combination of high pressure of 400 bar and a high temperature of 100°C are chosen, because these conditions typically cause many commonly available seal designs and materials to fail within less than 50.000 double strokes. The results of one PU seal (OMK-PU) made from the hydrolysis resistant 98 AU 30500, 4 other PU and one PTFE seal are shown in Figure 4.4.

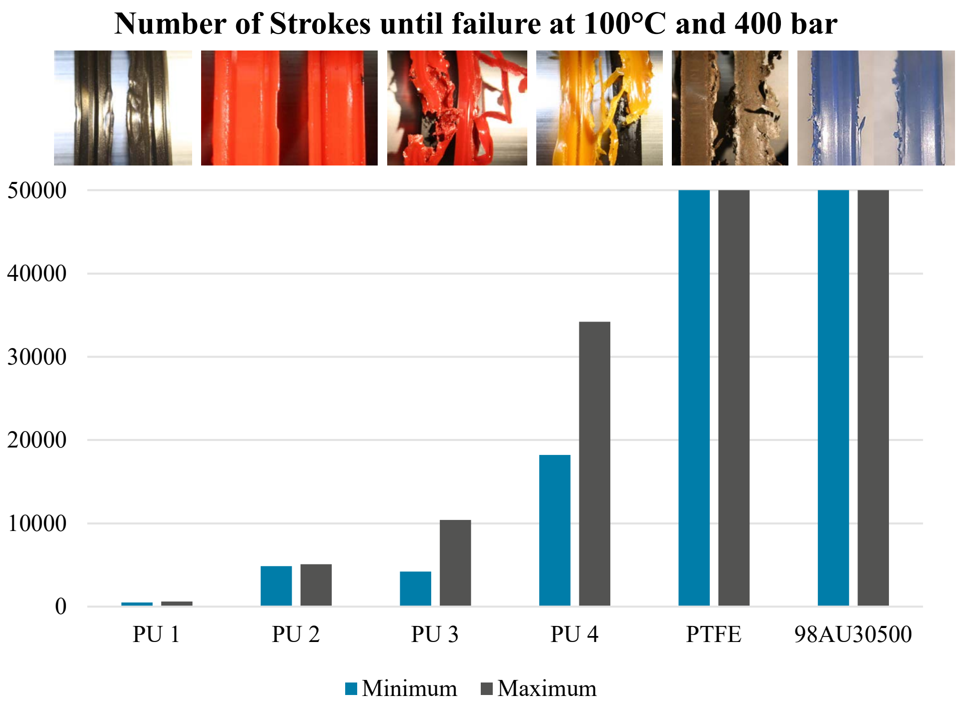

Figure 4.4. Comparison of the Life Time of one PTFE and Multiple PU Seals.

All investigated PTFE seals survived the endurance test. Out of the five PU seals, only the seal made from 98 AU 30500 managed to survive the endurance test with all five specimens. Only one of the other four PUs managed to survive with one module up to 50.000 double strokes. The reason for the premature failures can be observed in the pictures of the seals after tests. Severe extrusion occurred in all prematurely failed seals, some of which even broke apart. The results are in line with the material compatibility tests shown in section 3.2, where huge differences between the different investigated PUs occurred.

It is worth comparing the PTFE and the 98 AU 30500 seals after the endurance test. While PTFE seal already shows severe extrusion patterns, the PU seal only shows minor damage. The presence of large extrusion damage usually indicates that only limited life time remains. In addition, if parts of the extrusion damage breaks lose from the seal, they can get stuck in other hydraulic components like valves causing down time and damage.

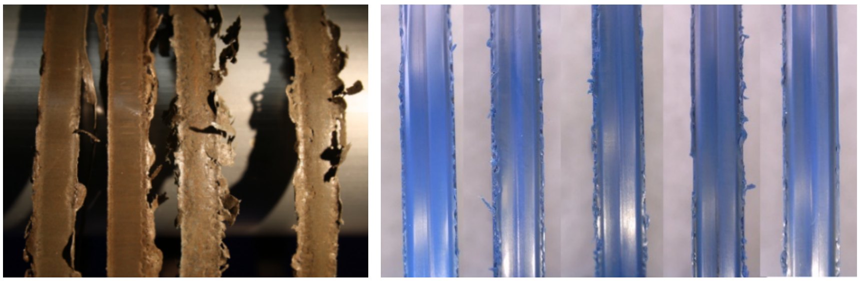

Figure 4.5. PTFE (left) and PU Seal (98 AU 30500, right) after the Endurance Test.

5. SUMMARY AND OUTLOOK

Motivated by international discussions about increasing regulations for PFAS substances, this paper investigated where PFAS containing materials are used in hydraulic sealing systems. For the scope of this paper, the focus of further investigation was on PTFE and its unique properties as a sealing material. After evaluating the beneficial material properties of PTFE, the paper discussed the potential of using polyurethane (PU) as an alternative material for hydraulic seals.

Some main advantages of PTFE over PU include lower friction and wear coefficients, better temperature and media resistance. To investigate whether PU can serve as a viable alternative, the practical consequences of these advantages in hydraulic applications were investigated using both material and seal tests.

In terms of material compatibility, it could be found that some PUs show severe degradation of material properties even after few weeks of immersion in typical hydraulic fluids at temperatures between 60 and 110°C. However, there are also hydrolysis resistant PUs like 98 AU 30500 which showed stable behavior during the immersion even after 12 weeks of severe exposure to temperature and different media. This indicates that there are PUs with sufficiently high media and temperature resistance for the majority of hydraulic applications.

For comparing the performance of these materials used in a hydraulic piston seal, a test rig was used. While some PU seals showed severe degradation even after less than 10.000 double strokes during an endurance test at 400 bar and 100°C, the material 98 AU 30500 reached the full 50.000 double strokes with less apparent damage than the PTFE seal. In terms of leakage and friction the investigated PU seal Simko 300 also showed better behavior than the PTFE seal.

Before concluding this paper, it should be noted that sealing systems are highly complex tribological systems. Therefore, especially in demanding applications, the selection of sealing design and material should be carefully adjusted to the conditions and needs. Thus, a general statement about whether "PTFE or PU is a better sealing material", cannot be made. Especially where low break away friction forces and low stick slip probability are desired or high temperature and aggressive media is present, PTFE seals can rely on the core strengths of its material. However, the results presented here demonstrate that even at high pressures and temperatures, choosing a highly resistant PU like 98 AU 30500 as a sealing material can deliver not only comparable but superior results in terms of endurance, friction and leakage.

6. DECLARATION

For the creation of this paper, the authors used the assistance of AI tools for editing and revising parts of the text and for accelerating literature research. All AI outputs and references were reviewed, edited, and verified by the authors prior to inclusion.

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BIOGRAPHIES

Niklas Bauer received the bachelor's and master's degree in mechanical engineering from RWTH Aachen University in 2017 and 2019, respectively. From 2019 to 2025 he worked in various positions at the Institute for Fluid Power Drives and Systems (ifas) in Aachen, last as chief engineer. He graduated in 2024 with a Doctoral degree about elastohydrodynamic simulation of pneumatic sealing systems. In 2025, he joined Freudenberg Sealing Technologies as Head of Advanced Development, where he is responsible for the development of new products for new markets. He supports the University of Dresden as a lecturer on the fundamentals of sealing technology.

Gonzalo Barillas received his Diploma (Dipl.-Ing. (FH)) at the former Fachhochschule für Technik Esslingen, today's University of Applied Sciences Esslingen in 1984, his thesis thema was Tribology of Ceramic Materials. He started then in 1985 as product developer at sealing company Merkel in Hamburg, in 1990 he joined Freudenberg Sealing Technologies in Schwalmstadt, where he worked in several positions in the development and business development of seals. His last position before retiring in Dec. 2025 was Manager of advanced product development at the Lead Center Fluid Power Industry. He supports the University of Dresden as a lecturer on the fundamentals of sealing technology.

Jürgen Hieber received his Diploma in Chemistry in 1993 and his Doctorate (Dr. rer. nat.) in 1996 from the University of Tübingen, with a doctoral thesis entitled *"Electrically Conductive Polymers"*. Since 1996, he has been employed by Freudenberg Sealing Technologies, where he currently serves as Head of Material Development for the Fluid Power Industry. During his tenure, he has, among other responsibilities, led the construction of a new polyurethane granulate production facility. He has delivered several technical presentations on polyurethane materials for sealing applications.

Martin Goerres graduated in Mechanical Engineering at RWTH Aachen University in 1999. He worked as Research Associate at the Institute for Fluid Power Drives and Controls (IFAS) until 2005. He joined Freudenberg Sealing Technologies (formerly known as Merkel Freudenberg Fluidtechnic GmbH) in 2005 where he worked in various positions. As Director Engineering and Innovation he is globally responsible for the Engineering at the Lead Center Fluid Power Industry. He has been serving as a reviewer and committee member for the international fluid power and sealing community.