Burckhardt Compression

PUSHING THE LIMITS OF PTFE-BASED SEALING ELEMENTS

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Compressors for a Lifetime™

In sealing technology, PTFE has become an established material in the low-pressure range. This pressure range is limited due to the lack of mechanical stability, which is why manufacturers often have to resort to costlier high-temperature polymers for medium and high pressures. However, these high-temperature polymers exhibit lower chemical resistance and require harder counterpart materials.

The newly developed Persisto® 870 pushes the limits of PTFE based sealing elements to higher pressures, resulting in a number of benefits. PTFE-based materials offer outstanding chemical resistance and are much cheaper than those made from high-temperature polymers such as PEEK. Furthermore, PTFE-based sealing elements can be used in combination with low-cost counterpart materials such as gray cast iron instead of nitrided or tungsten carbidecoated steels.

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Dr. Norbert Feistel received his degree in Mechanical Engineering (Dipl.-Ing.) from the University of Karlsruhe, Germany, in 1987. In 1988 N. Feistel joined the R&D Group of Burckhardt Compression in Winterthur. After approximately two years, in which N. Feistel's activities concentrated mainly on the labyrinth piston compressors, his responsibilities are now for the development of oil-free sealing systems. In 2002 he gained a PhD at the University Erlangen-Nuremberg, Germany, with a thesis on the operational behavior of dry-running sealing systems in crosshead compressors.

INTRODUCTION

In a piston compressor, seal and rider rings made from dry-running plastic compounds operating within permitted limits enable gas compression without the need for additional lubricants such as oil or grease. Plastics suitable for this purpose have almost completely replaced dry-running materials based on carbon or graphite.

The majority of modern oil-lubricated compressors also use plastic sealing elements. Metals such as gray cast iron or bronze are only used at very high pressures. The dominance of plastics over metals is not just due to the tribological features for such applications. Another important advantage of using plastics as a sealing element material is the fact that, in the event of insufficient lubrication, the sealing elements are worn while the counterpart surface remains free of damage. This allows for lower operating risks and a significantly reduced lubrication rate compared to metal rings.

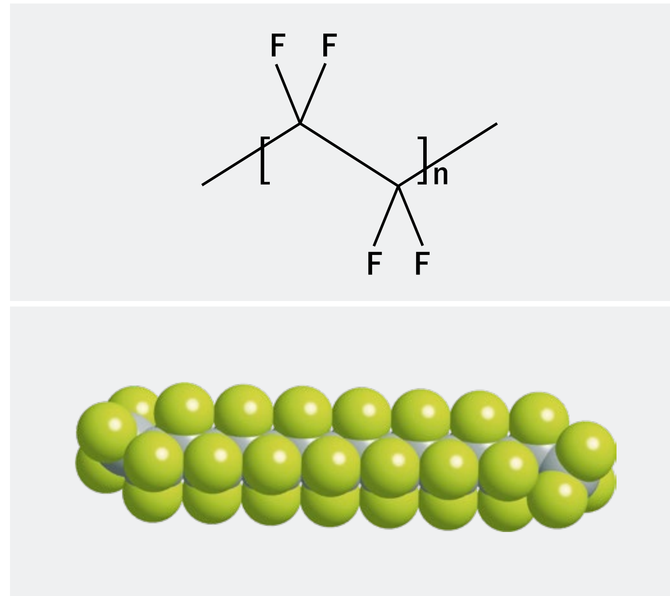
The best-known plastic for use in sealing elements is polytetrafluoroethylene (PTFE), commonly known as Teflon. It offers a range of positive characteristics for this application.

CHAPTER 1

CHARACTERISTICS OF PTFE AND HOW THEY ARE INFLUENCED[1]

PTFE is a semi-crystalline polymer consisting of carbon (C) and fluorine (F) with extremely long linear molecule chains (n to 10^6). The carbon chains in PTFE are completely surrounded by a layer of fluorine. This molecular structure gives PTFE its characteristic properties such as a high melting point, excellent chemical resistance and low surface tension, and allows for very low friction coefficients. The low surface tension leads to very low adhesion to other materials, which is why PTFE is often used as a non-stick material. But this can cause problems related to wetting, adhering or welding PTFE. The long molecule chains in PTFE display only very low intermolecular interactions, allowing them to slide over each other very easily in the crystalline areas. This leads to unwanted cold flow behavior (creep). **Fig. 1**

Fig. 1
Structural formula and molecular model of PTFE.



To reduce cold flow and improve the mechanical properties, PTFE is not usually used in its pure form in mechanically stressed parts but is instead reinforced with fillers. Inexpensive glass fibers are often used here, along with carbon or aramid fibers and other fillers such as carbon, graphite, molybdenum disulfide, bronze particles, etc. Fillers for use in sealing materials must be selected carefully, taking external factors such as gas, pressure, dry-running / lubricated and counterparts into account. Glass fibers, for example, can cause significant damage through abrasive wear if coupled with soft counterparts in a dry-running system, while graphite loses its lubricating effect in very dry gases. Ideally, different fillers can be combined to create a sealing material that offers the right mechanical and tribological properties for the respective application.

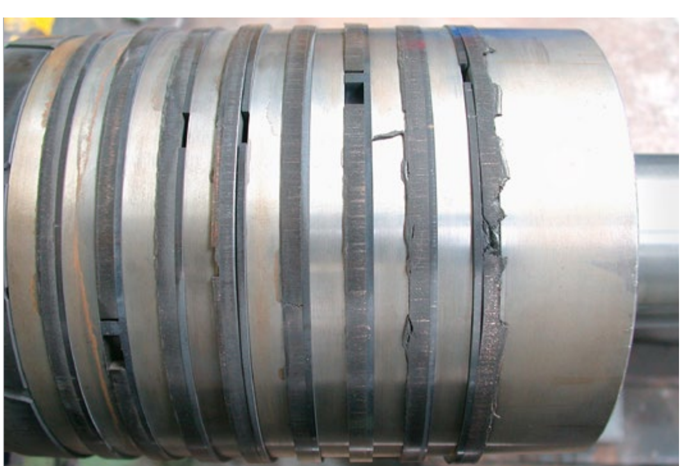
One major challenge when improving the creep resistance of PTFE is connecting the filler to the matrix. Due to PTFE's low surface tension, this usually takes the form of mechanical anchoring. The connection between the fillers and the PTFE matrix can be improved through either physical anchoring or chemical bonding agents. Fibers or polymer fillers with a rough surface, for example, adhere better to the PTFE matrix. Chemical bonding agents are used with glass fibers, which are usually functionalized with a corresponding bonding agent for various polymer based materials. However, chemical bonding agents can cause unwanted reactions when used as a sealing material in piston compressors. The corresponding rings are no longer suitable for universal use, e.g. for operation in oxygen. Roughening the filler surfaces to achieve better adhesion in the matrix is also not always sufficient for parts such as sealing elements that are subjected to high tribological stress.

CHAPTER 2

THE LIMITS TO USING FILLED PTFE IN PISTON COMPRESSORS

In dry-running, the use of filled PTFE materials is limited above all by a high wear rate and / or high temperatures caused by high friction. In oil-lubricated applications, by contrast, wear and friction are reduced to low values, assuming that the parts are lubricated correctly. Use is still limited here, however, mostly due to the aforementioned creep behavior under pressure and thermal load. As a result, sealing elements made from PTFE materials are usually only used at pressures well below 200 bar. The significant influence of temperature on creep resistance is another reason why permitted usage limits are difficult to define. It is not possible to make precise statements on the average temperature of individual sealing elements during operation. If these limits are exceeded, ring material can flow into the gap between the piston and the cylinder or between the packing cup and the piston rod. In extreme cases, this can lead to a complete failure of the sealing system. Design measures, such as large cross sections and support rings made from metal or high-temperature polymer, aim to counter the flow of filled PTFE sealing elements. Despite this, sealing elements made from filled PTFE are unable to cover the pressure ranges present in the piston compressor. **Fig. 2**

Fig. 2
Piston rings made from filled PTFE flow into the gap between the piston and the cylinder.



CHAPTER 3

HIGH-TEMPERATURE POLYMERS AS AN ALTERNATIVE

High-temperature polymers are usually used when filled PTFE materials cannot provide the necessary reliability. These materials, such as polyimides, polyaryletherketones or polyphenylene sulfides, offer better high-temperature strength than PTFE. Polyetheretherketone (PEEK) is a plastic compound whose bearing-grade variant is commonly used for sealing elements in piston compressors. Bearing-grade PEEK often uses PTFE, graphite and carbon fibers as a filler, commonly with a mass fraction of 10% of each. A PEEK material modified in this way offers impressive mechanical properties compared to a PTFE material filled with carbon or graphite. Its tensile strength of 18 MPa at 250 °C, for example, is higher than that of carbon graphite filled PTFE material at room temperature (just 10 MPa [2]. In industry, sealing elements made from these materials are used in oil-lubricated compressors at pressures of over 500 bar.

However, the high elastic modulus and low ductility of bearing-grade PEEK has a negative effect in sealing element assembly, dynamic pressure loading and wear compensation. Rings made from this material are usually very stiff, which prevents them from lying evenly and completely on the sealing surfaces. This can increase leakage rates. Despite its general suitability for dry-running with soft counterparts like gray cast iron, this material can also cause damage due to abrasive wear. Some sealing element manufacturers therefore recommend a minimum hardness of 40 to 50 HRC for the counterparts.

When it comes to chemical resistance, the fluorine polymers far outperform the high-temperature polymers. PTFE displays a virtually universal chemical resistance, making it suitable for use in almost all process gases except for coolants containing fluorinated hydrocarbons. By contrast, the chemical resistance of high-temperature polymers like PEEK, PI or PPS in the respective process gas must be checked precisely.

As a final consideration, high-temperature polymers are around three to five times more expensive than standard filled PTFE materials. This is due to both the significantly higher compound costs and the intensive production processes for semi-finished products, such as pressure sintering or hot isostatic pressing (HIP). In more cost-effective processes like injection molding or extrusion, the diameter of the semi-finished products is limited.

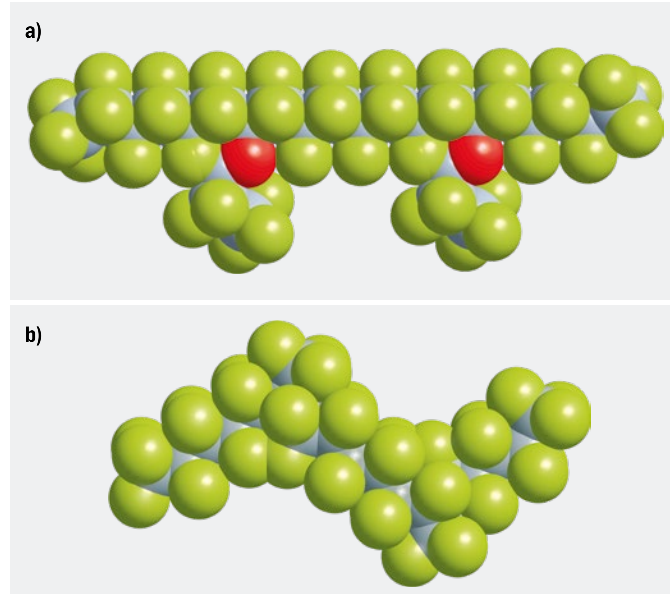
CHAPTER 4

FLUOROPOLYMERS WITH IMPROVED COLD FLOW PROPERTIES

Alongside the use of fillers to reduce cold flow, it is also possible to reduce creep by chemically modifying the PTFE itself. Introducing side chains both significantly reduces the chain length and effectively interrupts crystallization. This causes the crystalline areas to shrink and reduces cold flow.

The side chains are added via comonomers during synthesis. In industry, perfluoro (propyl vinyl ether) is mostly used with PFA or modified PTFE, while FEP uses hexafluoropropylene. The product is designated as modified PTFE or PTFE homopolymer if the comonomer content is ≤ 1%. If the comonomer content is > 1%, the product is designated as PTFE copolymer (e.g. PFA and FEP)[3]. The smaller molecule masses compared to PTFE lead to lower melting viscosities. This means that PFA and FEP, unlike PTFE, can be processed like typical thermoplastics as a molten mass. **Fig. 3**

Fig. 3
Molecular model of a) PFA and b) FEP



Subject to the processing methods available, it is also possible to reduce cold flow not just with fillers but by using another fluoropolymer or a mixture. It should be noted, however, that this can reduce both temperature stability and chemical resistance, depending on the type and concentration of the comonomers. The temperature limits are 260 °C for PTFE, 240 °C for PFA and just 205 °C for FEP.

It can sometimes be difficult to judge whether compounds are suitable for use as a sealing element material as the data on mechanical properties in the literature is usually the result of tensile tests. In piston compressors, the materials are mainly subjected to pressure loads. As a result, data from pressure tests tells us far more about a material's suitability. Figure 4 shows an example of two materials that display barely any differences in tensile testing but significant differences in pressure testing. When tested in a compressor, the material with the better pressure properties performed significantly better. **Fig. 4**

The newly developed Persisto® 870 has been optimized both in its polymer matrix and the filler to offer reduced cold flow and increased stiffness while maintaining low abrasion. In the pressure and creep test, it performs much better than the carbon / graphite or glass / MoS_2 filled PTFEs that have previously been used for these applications. **Fig. 5**

Fig. 4
Pressure / creep properties of two materials with virtually identical tensile properties. Tensile strength of material A / B = 9.5 MPa, elongation at break of material A = 6.2% and material B = 7.1%.

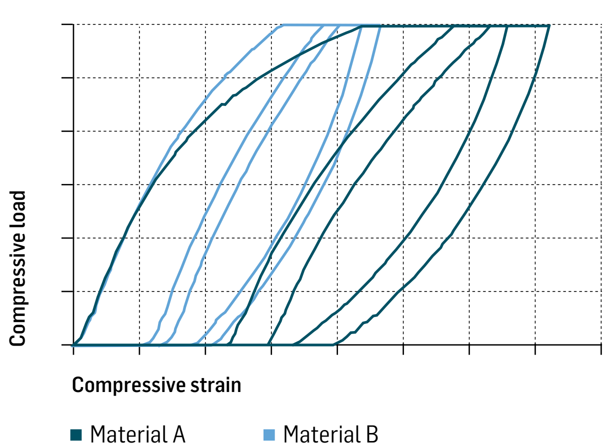
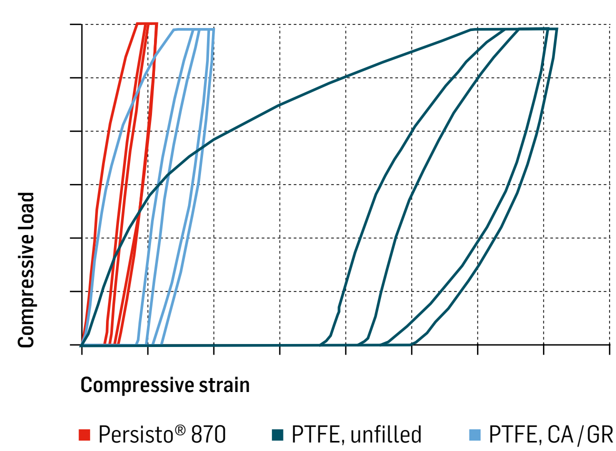


Fig. 5
Pressure / creep properties of Persisto® 870 compared to unfilled PTFE and PTFE filled with carbon / graphite.



CHAPTER 5

EXPANDING THE FIELD OF APPLICATION OF FLUOROPOLYMERS IN PISTON COMPRESSORS

Sealing elements made from fluoropolymers with improved pressure properties can be used in a piston compressor above the previously permitted limits of traditional filled PTFE materials. This shifts the field of application for the significantly more expensive high-temperature polymers to higher pressures and temperatures. It also eliminates the aforementioned disadvantages such as insufficient wear compensation, the need for hard counterparts and low chemical resistance.

Persisto® 870 is exactly this kind of mid-range material. The unique mix of various fluoropolymers and a special carbon fiber gives Persisto® 870 its improved creep behavior without having to use abrasive substances. This makes it suitable for use on soft counterparts. Despite the much-improved creep resistance, piston and rider rings made from Persisto® 870 are flexible and can adjust to suit the profile of the counterface. They are therefore easier to handle during assembly and disassembly.

Alongside good mechanical properties, ring materials must also display good tribological characteristics. As mentioned previously, the wear values of oil-lubricated friction pairings are usually much lower than those of dry-running parts. This results in higher requirements for the sealing systems used in lubricated compressors. Operators currently expect an uninterrupted service life of three to five years.

In order to verify the wear behavior of Persisto® 870, tests were conducted using packing sealing rings in an oil-lubricated process gas compressor. The most difficult factor during planning was the choice of suitable test parameters as standard oil lubrication rates require a very long operating duration in order to obtain reliable wear rates. **Fig. 6**

As a result, the lubrication rate for all tests was set at a value of one drop of oil per minute. This low lubrication rate led to measurable wear on standard plastic materials after a test duration of 100 hours. In addition to Persisto® 870, the tests were carried out on packing rings made from carbon / graphite-filled PTFE, carbon / graphite / glass fiber / MoS_2-filled PTFE and bearing-grade PEEK. The tests were conducted on a piston rod with a diameter of 50 mm coated with hard metal. The test medium was air, compressed from a suction pressure of 4 bar to a discharge pressure of 14 bar, with a maximum temperature of 177 °C and an average piston speed of 4.8 m/s. Figure 7 shows the wear rates measured under these conditions for the tested candidate materials. Note the poor values for the two conventional PTFE materials. In contrast, the new Persisto® 870 displays outstanding wear behavior during operation, along with a very low lubrication rate. This favorable behavior in so-called mini-lube operation provides the solution to the demand of many operators to keep the use of lubrication oil to a minimum. **Fig. 7**

With this combination of favorable mechanical and tribological properties, Persisto® 870 opens the door to new applications in oil-lubricated sealing systems. Although the material cannot fully replace expensive high-temperature polymers, it allows their use to be significantly reduced from current levels.

Fig. 6
Process gas compressor for investigating the operating and wear behavior of oil-lubricated sealing systems.

Fig. 7
Persisto® 870 displays excellent wear behavior in operation with a low lubrication rate.

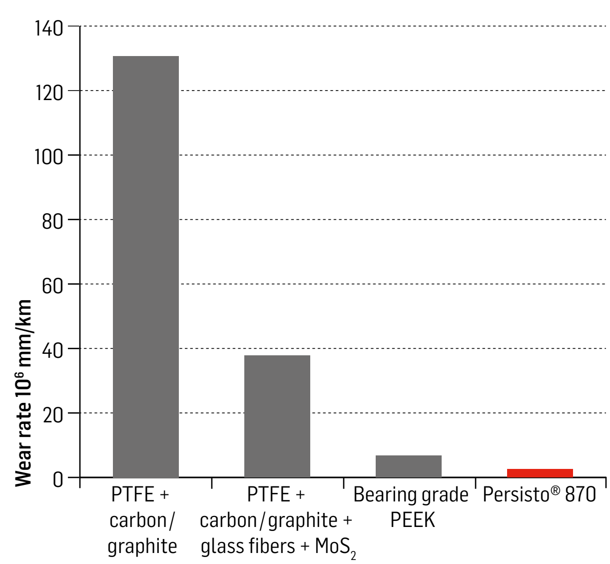


Table 1
Comparison of properties in various sealing element materials.

Ring material	**PTFE + carbon / graphite**	**PTFE + carbon / graphite + MoS_2 + glass fibers**	**Bearing-grade PEEK**	**Persisto® 870**
Flexibility	good	good	poor	**good**
Creep resistance	poor	better	very good	**good**
Abrasiveness	low	high	high	**low**
Cost	low	low	high	**low**

A typical example for the use of Persisto® 870 in a piston compressor is the third stage of an oil-lubricated refinery compressor for compressing hydrogen from a suction pressure of 90 bar to a final pressure of 190 bar. The cylinder diameter in this stage is 330 mm and the counterpart is made from gray cast iron. Table 1 shows a comparison of properties of two standard filled PTFE materials with a bearing-grade PEEK. When all properties are taken into account, it is clear that Persisto® 870 is best suited for this application. **Table 1**

Nomenclature

PTFE Polytetrafluorethylene
PEEK Polyetheretherketone
PI Polyimide
PPS Polyphenylenesulfide
PFA Perfluoroalkoxy polymer
FEP Fluorinated ethylene-propylene copolymer

Literature

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Chapter 1 + 2, Plastics Design Library, 2000

2 N. Feistel
Trocken laufende Dichtsysteme in der Praxis – neue Herausforderungen durch neue Materialien (Dry-running sealing systems in practice – new challenges from new materials)
Industriepumpen + Kompressoren 3, September 2007, S. 141-148

3 DIN EN ISO 12086-1:2006-05

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23.25.14.40 – 04/2018 – Printed in Switzerland on FSC certified paper

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