FRANKFURT, 07.09.2023

PNEUROP C 18 "Process Gas Compressors"

Draft PN18 technical position paper

Table of content

1 Executive Summary

Pneurop is the European association of manufacturers of compressors, vacuum pumps, pneumatic tools and related equipment. Pneurop members are national associations, representing more than 200 manufacturers in 7 EU Member States, the United Kingdom and Turkey. The European market turnover of the represented company exceeds 20 billion euros.

Pneurop agrees that PFAS should only be used where strictly necessary and fully supports the restriction of PFAS into the environment. However, as there are no alternatives available today and in the foreseeable future for critical applications, the use of those PFAS containing applications should remain possible in a controlled way (collection, recycling, appropriate disposal). We must avoid regrettable substitutions for our customers in the medical, food and beverage, energy and many other sectors.

PNEUROP
THE SECRETARY GENERAL
BluePoint Brussels
80 BD A. Reyers
B-1030 Bruxelles
Tel +32 2 206 68 66

E-mail secretariat@pneurop.eu
www.pneurop.eu

Committee's Chairman:
M. Schulz
SIEMENS Energy

Committee's Secretary:
Dr. A. Brand
VDMA

Secretariat PN 18
VDMA – Fachverband Kompressoren
Druckluft- und Vakuumtechnik
Lyoner Straße 18
D-60528 Frankfurt
Tel +49 69 66 03-1283
E-mail andreas.brand@vdma.org
www.vdma.org

Kompressoren, Druckluft- und Vakuumtechnik

Even though the amount of PFAS in our products is very small (<< 0,1% by weight), there are PFAS containing parts in all of them. The impact of a ban in Europe will imply a closure of the European factories of our members with 100% loss of employment (>>10.000 people) and revenues (>20b€).

Pneurop is submitting four papers to elaborate in more detail PFAS and its use, value, and challenges of our major product types.

This paper deals with the specifics about PFAS and process gas compressors (Pneurop Committee 18).

1.1 Pneurop Committee 18 (PN18, Process Gas Compressors)

This position paper outlines the position of process gas compressor manufacturers represented in Pneurop PN18. It shows main applications of process gas compressors as an inherent product within a broad area of industrial processes having significant impact on the overall European Industry. This includes activities related to renewable energy applications and overall decarbonization of industry including carbon capture applications.

The paper explains main rationale for the application of PFAS products within process gas compressors and announces expectation about significant compromises on product- and safety requirements as well as economic impact without applications of those. In addition, alternative designs features will need to gain market acceptance by reference applications and a renewed certification process for specific hazardous applications. The custom design of process gas compressors will complicate those qualification processes, which, amongst others, will have immediate impact on relevant growth areas within the field of decarbonization and renewables. The process gas industry is primarily interested in application of fluoropolymers (fluoroplastics and fluoroelastomers) unless it is stated explicitly differently.

The overall business impact on industrial compressor applications as described within this paper indicate a need for advanced consideration for a controlled use of those materials in reference to a circular economy, at which the industry could expand on already existing regulations for waste management. Most PFAS materials as used in industrial applications are materials of low concern, compared to monomers which are more harmful. In addition, process gas compressors operate in a closed system, where potential PFAS emissions can be controlled as well. Release of PFAS from a process gas compressor is considered to only occur when a component is replaced or when the compressor reaches the end of its life. In such cases, it can be managed to avoid a release of PFAS into the environment and PFAS components can be safely disposed of, recovered, recycled or reused.

2 The Value of Process Gas Compressors for Energy Transition and Economy

The production and the transport of gases as well as process related gas treatment is given an essential part of overall industrial economics, while process gas compressors are an inherent part of the related process chain. Base products as derived from those applications lead to a significant variety of end-products as required for further industrial use.

Initially, the application of process gas compressors can be categorized in upstream-, midstream- and downstream, while every area of application owns specific boundary conditions. The following list provides exemplary applications:

» Hydrogen compression for transportation, distribution, and handling of hydrogen in all todays and future applications where it is supposed to replace fossil fuels, reduction agents etc. Please also review the Hydrogen Europe Position Paper on PFAS [1]

» Supercritical CO2 compression, storage, and transport

» Carbon dioxide compressors for Carbon Capture, Sequestration and Storage, beverage supply, reinjection and various industries

- Compression of Biomethane
- High-temperature air compressors for Compressed Air Energy Storage
- Ammonia compressors for fertilizer plants and long-distance transport of Hydrogen
- Natural gas production, handling, refining (containing hydrogen sulfide), transportation and re-gasification
- Compression, storage, and transport of Liquified Natural Gas (LNG)
- Oxygen processing and transportation in medical, wastewater treatment, energy industry, and various industrial applications
- Steam compression, also including corrosive constituents.
- Compressors for Air Separation
- Syngas compressors, also for power to liquid for kerosene
- Cracked gas compression in coal gasification and olefin plants, various chemical applications
- Hydrocarbon compression for various cooling or refrigerating cycles / Refrigerant compression for large-scale air conditioning and heat-pumps
- Synthesis gas compressors in methanol plants
- Ethylene oxide compressors in chemical plants providing primary products for pharmaceuticals, textiles, fibers, detergents, agrochemicals etc.

Process gas compressors as applied within the upstream market need to resist untreated gas compositions, where gases, amongst others, show corrosive properties. Similar applies to downstream applications supporting the chemical industry, where gases show acid or basic conditions and might be considered toxic, hazardous or explosive as well. In both areas of applications, boundary conditions as mentioned require PFAS products with its inherent chemical- and temperature resistance as well as specific tribological properties to maintain equivalent product- and safety-requirements. The unavailability of those product properties will even take influence on chemical processes not developed yet.

For midstream applications, PFAS materials are a key product to comply to regulations for fugitive emissions. Further, the market area of Liquified Natural Gas (LNG) requires application of process gas compressors with consideration about cryogenic temperatures. In this specific context, there is no equivalent in temperature resistance of sealings compared to PFAS products, which need to be considered critical for the approach to replace Russian gas with an increasing amount of LNG within the European Union.

As valid for new build applications, specific focus has to be given to service-applications as well. In those applications the requirement for substitution of PFAS products during continuous service intervals will significantly change the product design, product properties and maintenance aspects as well as spare parts management. In addition, it might get in conflict with relevant safety aspects and additional regulations as required for compressor operation, which might make existing compressor products unserviceable. Under consideration of limitations about the overall manufacturing capacity for new compressors, this will have an immediate impact on existing infrastructure and relevant product chains.

Beyond the traditional applications of process gas compressors, they are meant to support renewable energy applications. Here as well, PFAS products are applied to not compromise on product and safety requirements. This especially applies to the compression of hydrogen and oxygen, but also to compression of CO2, if blue hydrogen is under consideration. Blue hydrogen is created by conventional processes, where CO2, as a by-product, need to be transported and finally compressed for storage. Considering targets as defined in the agreement about the European Hydrogen Backbone [2], process gas compressors will be a key product for this approach. PFAS products, e.g. sealings, will ensure safety requirements and ecologic requirements for such applications, while alternative approaches will not be able to show equivalent product efficiency, because of the specific tribological properties of PFAS products.

Examples as shown illustrate the meaning of PFAS products for process gas compressors as an inherent part of main industrial process but are not limited to the applications as mentioned above. To not compromise on product- and safety-requirements and to risk main economic and ecological initiatives within the European Union, advanced consideration in regard to a controlled use of those materials in reference to a circular economy might apply. This approach would result in an unlimited derogation of PFAS materials in industrial applications of process gas compressors, while extended effort and cost in reference to a circular economy will promote an exchange of PFAS materials, if reasonably possible.

3 PFAS Application within Process Gas Compressors

Process gas compressor manufacturers supply centrifugal compressors, reciprocating compressors, expanders (and pumps) for a broad range of applications in which hazardous, corrosive, and/or flammable gases are involved. Typical applications range in operating conditions from vacuum [50Torr] to more than 600 bar(a) pressure level, temperature level range from cryogenic i. e. lower than -200°C, to above 300°C. Reciprocating compressors also deal with Hydrogen fueling stations (cars, in future also trains, planes etc.), where pressures even up to 950 bar(a) are realized; a demanding application at high pressures and high temperatures, were high wear resistance of PFAS-based sealing elements are needed.

In regard to process conditions as mentioned, PFAS materials and dominantly fluoropolymers are an essential building blocks of a reliable compressor design. It is mainly the concurrence of high-pressure, high temperature and the chemical compatibility, which limits the use of PFAS free alternatives. For this reason, it might be considered certain that there are no general alternatives available for process gas compressors and that a ban of PFAS will prevent the execution of certain jobs and also slows down the transition towards a greener industry in Europe. The following sections are providing more technical details in reference to individual application areas, while it does not claim for overall completeness.

3.1 Sealing applications

According to alignment with sealing solution providers (O-rings and gaskets) and review of compatibility data published in their product brochures, there are elastomeric solutions for gas streams having either an apolar nature (linear or branched aliphatic compounds) or having a pronounced polar nature (short chains or inorganic acetic acid, Chloric acid). However, when both characteristics are present either in the same molecule, e.g organohalide, aldehydes, ketones, amines, PFAS containing elastomers are the only documented available alternative. Similar compatibility issues can be expected in mixtures of polar and apolar components. Since most of process gas compressors applications operate at higher temperature with a broad variety in chemical constituents, this means that alternatives may not exist for process gas compressors applications and fail quickly and/or age and harden in no time. The high- speed characteristics of process gas compressors applications means that nicks because of impacting particulate is a scenario to consider, too. In a hardened condition, the elastomeric material's damage tolerance decreases quickly favoring a scenario in which those nicks suddenly grow into a catastrophic seal failure.

3.1.1 Centrifugal Compressors

Flexible sealing elements, typically elastomeric O-rings are commonly used to contain fluids within pressurized cavities of turbomachinery at the interfaces between adjoining components. For piping connections, gaskets are a common employed solution. Regardless of the geometry of the elastomer, the material needs to be able to deform under the combination of clamping, bending and torsional deflections and fluid pressure, filling the surface irregularities and accommodate the manufacturing tolerances. In order to work correctly as a sealing medium, the part is being compressed which is typically 15-20% compression set for O-rings. This preload creates the necessary surface area for the elastomer to fill the irregularities and the friction force to keep it localized in the intended location. Under the described load conditions, the material needs to deal with prolonged times at elevated or cryogenic conditions in the presence of a wide variety of chemical constituents. At elevated temperature, the polymer softens lowering its strength and making it more prone to chemical reactions with the contained fluid causing swelling, cracking, and/or aging. While at low and cryogenic temperature in addition to thermal shrinkage, it becomes brittle unable to perform its sealing function.

Among the elastomers, fluoropolymers have the best chemical resistance, excellent aging characteristics, widest operational temperature range and a high resilience/low compression set. Because the current fluoropolymers are having such a broad spectrum of good to excellent properties, it is hard to find a suitable alternative that has longevity hard coded in its structure as does PFAS. Besides characteristics at high temperature, also safeguarding properties at low temperature is considered a technical challenge.

It is a misconception that elastomer selection is a simple screening exercise in which the tabled temperature limits and chemical compatibility are overlayed. The reported tables can merely be used to exclude certain alternatives rather than as an assurance that it will work. Compatibility data was screened from commercially available O-rings for liquid exposure, and it was screened from ISO 1114-2 for gas exposure. It was observed that for liquids about 1 out of 3 did not have a non-PFAS alternative at room temperature and for gasses 1 out of 4 did not have an alternative.

The reported material groups are not monolithic material groups. Besides differences in base polymers and cross-linking agents, the presence of fillers, plasticizers, anti-degradants (Antioxidants, Antiozonants, Protective Waxes), processing aids and pigments can alter properties significantly. Many specialized grades are being used to tackle specific challenges and process gas compressors are benefitting from these grades in collaboration with sealing solution providers. Examples of these grades include higher chemical resistance, lower temperature resistance, solvent resistance.

For gaskets and valve packing, the tracing whether they contain PFAS is an even bigger challenge. Besides the fibers being treated and coated, lubricants are being used to enable higher strength and better deformation characteristics and seal off crevices within the graphite gasket. The engineering of these structures is done by process gas compressors suppliers. In an analogue way as the O-ring gaskets, gasket and packing selection are done and should be understood in an industrial ecology of suppliers-customer relationship.

In turbomachinery, elastomers are often being pushed to their limits in which the deformation of the surrounding parts needs to be accommodated in addition to the elastomer's thermal expansion, swell, creep and stress relaxation, shrinkage, and aging effects. Material selection is often a collaboration between sealing solution supplier, process gas compressor manufacturer and material selection could be governed by customer specification because of its successful use elsewhere in its plant.

3.1.2 Reciprocating Compressors

For reciprocation compressor sealing elements, PTFE can form a unique tribo-film (also called transfer film in excessive scientific literature) to reduce friction and wear. Thus, sealing elements out of PTFE can last much longer (factor of 3 to 10) compared to other high-performance polymers. Moreover, the aliphatic structure of the molecule is responsible for the flexibility of PTFE. This leads to a higher sealing efficiency (factor of 2 to 5) compared to other high-performance polymers. There is no alternative polymer available and nor will be in the future, as the high sealing efficiency is strongly connected to the flexibility of the PTFE material. This flexibility depends on the aliphatic structure of the polymer chains. Aliphatic polymer chains can easily be broken by temperature, chemical or other harsh conditions unless they are protected by the strong C-F bond along the backbone. Thus, the high sealing efficiency at heavy duty applications can only be achieved with polymeric molecules such as PTFE.

Alternatives, especially high-performance polymers like PEEK, PPS or Polyimide will be much more expensive. More important, the lifetime of sealing elements based on these aromatic (non-aliphatic) polymers will be much lower and leakage rates will be much higher. At a compressor test bed of a spare part manufacturer, several tests were conducted in the past for comparing lifetime and sealing efficiency of PTFE based sealing elements compared to other high-performance polymers like PEEK. Lifetimes of the sealing elements are dropping down to 10 to max. 20 % of PTFE based solutions and leakage rates are increasing by a factor of 3 to 5. Therefore, it needs to be considered a significant threat for the environmental protection as, for example, might be caused by a significant leakage increase of CO_2 at breweries or a leakage increase of CH_4 at biogas plants. Moreover, due to gas losses the power consumption of the corresponding reciprocating compressor application will increase to compensate the amount of process gas needed.

In reference to section 3.1.1 and 3.1.2, please also see the position of the European Sealing Association (ESA) relative to the European proposal for PFAS regulation in relation with the Sealing Industry [**3].**

3.1.3 Specific Examples for Sealing Applications

» Hydrogen liquefaction

In these applications, temperature as low as 20K (-253 °C) are required. The challenge is maintaining flexibility of elastomers at these temperatures either because of operating below the ductile to brittle transition temperature (temperature at which crystallization of the polymer occurs lowering its ability to deform or that functional groups are creating strong steric hindrance during deformation at these low temperatures. There are not many rubber alternatives available at 20K. Static seals are commonly using (reinforced) PTFE with a spring seal to overcome thermal shrinkages or PCTFE. Both are part of the PFAS. Graphite is able to seal at these temperatures, too. Besides having higher friction, it remains a challenge in finding an appropriate filler material that is ductile enough to prevent crack initiation and could support graphite in developing the lubricant film. Cryogenic applications are not having enough water content for graphite to develop its lubricating properties.

» Oxidizing Environments

Because of the high explosion risks involved in these environments, there is long list of qualifications and legislation to comply to. Moreover, there is a strong reluctance to change the current materials to an alternative one. The European Gas Association (DOC 27/23 Compressors for oxygen service) refers to a report of BAM M034-1 in which the non-metallic materials are listed that can be used in oxygen environments. This is a list of commercially available non-metallic substances that are qualified for enriched oxygen service. According to their safety or technical datasheets, all listed liquid lubricants report having various degrees of fluorinated substances in their structure (PTFE particles, PCTFE, PFPE to name a few).

Managing and understanding these effects and their interactions are necessary to contain the compressed gasses. Besides being used in static application, elastomers are being used in inlet guide vanes as dynamic seals. This means that besides the static design consideration, size limitations are in place to keep speeds limits in check to minimize wear tendencies, there is a need for tear resistance to prevent the growth of defects in these materials.

Also, environments that are exposed to quick decompression rates, should have limited cross section. Smaller volumes of elastomers mean shorter diffusion lengths and higher resistance towards rapid decompression type of failures.

3.1.4 Safety Aspect of Proper Sealing Method and Compounds

The sealing requirements of the compressor and expander must consider multiple constraints. The seals must remain compliant during operation to properly seal the high pressure/high temperature gas from escaping into the environment where harm may come to personnel and equipment in the area. This leakage may be internal to the machine, as in the case for interstage seals and eye seals in pumps, expanders, and compressors, or external to the machine, as in the case of end face mechanical seals. The former results in a loss of efficiency, possibly process contamination or unexpected surge behaviour and the latter results in environmental pollution or hazardous chemical cloud releases.

Flammable gases must be contained to avoid the creation of hazardous area where fire and explosions would occur injuring personnel and damaging equipment.

Gases containing various corrosive and oxidizing agents require the use of suitable materials that are both compatible with the gas and able to operate as a leak-proof seal in containing the pressurized gas or vapor. Considerable danger exists if a sealing mechanism fails and releases the corrosive/oxidizing gas at high temperature or as a high velocity jet into the area of the personnel which are operating or inspecting the equipment.

Improper sealing of corrosive gasses can adversely affect the material properties of the high-speed rotating parts and/or pressure retaining components which can lead to premature catastrophic failure of the equipment. If a seal would leak corrosive gas into a cavity which is not designed to withstand the corrosive environment, general corrosion could occur thinning the walls and particle polluting other actuating equipment (such as Inlet Guide Vanes). Worse and more catastrophic scenarios include stress corrosion type of cracking in which ductility of the metallic materials gets compromised and pitting and crevice corrosion in localized corrosion causes tunnels and cavities below the surface. Leakage and rupture are both scenarios that can evolve from this localized corrosion. This type of interaction may already occur at very low concentrations.

Another scenario which may arise, is leakage of gas into the lube oil system altering the oil's film build up characteristics. This may impair the reliability of the drive train and thus may cause accelerated degradation of bearing and gears.

Just to put things into context: The power of the compression equipment can range from 500KW to over 40MW. Should this equipment suffer from catastrophic failure there would be danger to personnel and nearby equipment due to the energy release of the compressed gases, lack of material containment or possible electrical arcing/discharge.

3.1.5 Valves and Dynamic Sealing

The safe operation of the compression/expander equipment is dependent on critical valves such as the recycle valve which provides surge protection, automated isolation valves for the safe shutting down of the process equipment, and pressure safety valve [PSV] which are needed for the protection of process piping and equipment. The operating conditions of these valves are the same as those of the compression / expansion equipment and must maintain good operational performance to allow for safe operation of the entire system while containing the compressed gas.

For valves, both reliable dynamic sealing and actuation is needed. Other solid lubricants/dynamic seals require higher clamping forces for the same mass leakage rate. This higher clamping force is expected to cause higher wear or friction anomalies. Reliable and low friction is important as it determines the responsiveness of the valve in operation. In a report of Emerson, graphite technology was compared to PTFE based technology for both rotary as sliding stem valves. The graphite valves have a higher packing friction (because of the higher clamping) compared to the PTFE based packings to meet the requirements for fugitive emissions of the respective gas mixture. This higher friction may cause hampering movement of the valves and non-ideal friction behaviour. At lower temperatures graphite's lubrication ability seems to be lower restricting the mobility of the stem. This explains why graphite packings are more often used for high temperature applications.

Further, resilient [soft] valve seats are required to provide proper internal sealing in isolation valve applications. Lack of pressure containment can cause over pressurization of the process equipment and environment release of the gas through safety valves or vents. Equipment which is downstream of the valves may be damaged and fail due to operation at higher than design pressures. Furthermore, it may cause product contamination and process instability issues within process gas compressors customer's chemical processes.

3.1.6 Sealing against Fugitive Emissions

Currently the PFAS based technology was used to lower fugitive emissions in Oil and Gas business and new legislation was built around it. The acceptance limits for Europe are covered by the ISO 15848. The minimum accepted leakage rate is 50 ppm for methane and 1e-5 mg/(s*m) for helium. When customer spec out these leakage rates, process gas compressor manufacturers and its suppliers should be able to provide these for them in the respective pressure and temperature. Graphite packings and die pressed graphite will have remaining porosity and/or gaps and crevices within its fibrous structure that will allow gasses to permeate. This puts a ceiling on the graphite technologies sealing ability. PTFE as semi-crystalline material doesn't have that drawback of porosity and is limited by the solubility of respective gas into fluoropolymer or elastomer.

3.2 Minimizing erosion damage by coatings

Compressor such as steam compressors often suffer from corrosion, erosion and erosion-corrosion damage. To minimize damage because of entrained (corrosive) liquids and salts, an electroless Nickel coating is used with co-deposited Teflon particles. These electroless Nickel coatings are harder than steel and minimize the liquid impingement type of damage. The presence of the Teflon increases corrosion performance as it is hydrophobic, and it is resistant to many chemicals. Removal of the coating would cause rapid thinning of the impeller or guide vane blades, causing blade fracture. As soon as a blade break (guide vane or impeller blade), the impeller would become unbalanced causing the compressor core to fail. Moreover, the hydrophobic and oleophobic nature makes that the coating also serves as an anti-fouling type of coating.

Further, fouling, or the buildup of contamination on the compressor's internal surfaces should be managed in a compressor. Similar as in thermal protection coatings, it could be adhering of ductile material, but it could also involve tribo-chemical polymerization reaction. The adhering material can alter the compressor aerodynamics, could create under deposit corrosion and reduce efficiency and increase vibrations. Presence of hydrophobic and oleophobic agents such as PTFE provide chemical repellence towards impact process contaminants.

3.3 High temperature motor cabling

PFAS compounds are often used for high temperature type of insulation material. The advantage in process gas compressors designs is that PFAS guarantees a high compatibility with environmental conditions and a higher coiling density. There are still discussions about non-PFAS material available for the cables in expander using magnetic bearings. The consequences might be that resources need to be spent on electrical certification and that the wiring might be less dense. Moreover, the shielding design might need to be revised when cabling would be exposed to process media. The magnetic bearings might contain PFAS as well however this is also still in discussion.

3.4 Coatings for bolts in Oil and Gas environments

Bolts need to ensure the clamping force in connections and are responsible for a leak tight design. Oil and Gas plants often need to deal with sour gas environments. H2S is poisonous at low concentrations and therefore release need to be avoided. Moreover, wet H2S has a unique interaction with metals and may cause stress corrosion cracking as it catalyses hydrogen pick up. Like hydrogen embrittlement, these corrosion phenomena cause a lower damage tolerance, higher sensitivity of fatigue failures. It is often a challenge finding suitable high strength bolting materials in a sour gas environment (H2S). Harder and stronger materials are more sensitive to this type of degradation and can therefore not be used. This means that clamping force for ensuring the leak tight design needs to be spread over more bolts. In the most corrosive applications often only Nickel age hardening type of material are suitable. Besides the higher cost of these materials, they have an inherent other disadvantage: Galvanic corrosion. Besides having the risk of having higher corrosion rates of the flange itself, the galvanic corrosion reaction may cause additional ingress of hydrogen worsening the local expected conditions. To mitigate these types of trade-offs and complications, oil and gas applications relied on XYLAN® coatings for bolts. These coatings provide low friction during assembly and good corrosion resistance over a wide temperature range. Because of its insulating properties, galvanic corrosion is not a concern. Because of its excellent shielding properties, high strength steel bolts can still be used. Moreover, since general corrosion is avoided, these fasteners can often be re-used after inspection.

3.5 Corrosion protection for process instrumentation

Besides bolts being protected, also process instrumentation needs to be shielded from harmful chemicals entrained in the process. Coatings, membranes, and liners are being used to protect the reliable read out from sensors such as pressure, temperature sensors and tachometers. Wrong read outs may cause wrong actuations in the control system or even may have repercussion on the coded safety measures.

There are various strategies to separate the sensor from the corrosive medium while keeping the sensitivity of the sensor high enough to detect changes in the process. Fluor based coatings and diaphragms are two commonly employed strategies to protect the transmitters. PTFE and PFA are two commonly used materials. As already discussed, the anti-stick properties avoid fouling interference on the signals.

4 Conclusion

As shown, PFAS materials and dominantly fluoropolymers are an essential building blocks of a reliable compressor design, while process gas compressors are particularly affected in thermally-, chemically- and safety- challenging applications. PTFE as major fluoropolymer and many fluor-elastomers do not have an alternative in numerous industrial applications. The superb properties of these fluoropolymers and fluor elastomers make them suited for critical applications such as process gas compressors in which a lack of containment involves immediate threats to human life and environment. Therefore, the development of direct substitution is a challenging endeavour with an uncertain outcome, which will also bear compromises in quality, performance, safety, and reliability. Alternatives cannot be implemented at the expense of safety, environment, or reliability. For this reason, a ban of PFAS products might even disable future application of process gas compressors within certain applications, which will have direct impact on relevant product chains.

Process gas compressor manufacturers are convinced that due to the unique setting of having and developing for equipment at sites of customers with a strong awareness of waste disposal, application of PFAS materials can transition to a more circular economy, at which the industry could expand on already existing regulation for waste management. Consequently, the usage of PFAS – for example fluoropolymers, a sub-group of PFAS not classified as hazardous by the CLP Regulation – should be permitted for continued usage until further notice as they are critical to the process gas industry as well as EU's green transition. Manufacturers will target on replacement of PFAS-products where applicable in non-critical applications. But if there is no reasonable substitute and most likely will not be available in the future the approach of choice needs to be a controlled circular economy. A stronger emphasise on the end-of-life phase in the life cycle management shall be given. In reference to FPP4EU view on the proposal for a restriction on per- and polyfluoroalkyl substances (PFAS) **[4]** the adoption of a sustainable regulatory framework is encouraged. Chapter 5 Annex is giving scenarios how a circular economy for process gas compressors could apply.

5 Annex: Examples for a circular approach of PFAS for process gas compressors

A circular approach of PFAS use could be explored together with customers and suppliers through a (reuse), reduce, recycle and a controlled disposal program. In the following, examples for a possible way forward for process gas compressors are given:

- REUSE: It can be evaluated whether static seals, which did not degrade in its specific application, can be washed, inspected and refurbished.
- REDUCE: Focus on essential use of PFAS for critical applications, the continued process of identification of PFAS use is essential. Similar to other material compliance processes, PFAS can become in first instance a declarable, allowing industry to evaluate the entanglement of PFAS in its supply chain. From this list, phase out projects can be started lowering the amount of PFAS entering non-critical new designed compressors.
- RECOLLECT AND RECYCLE: For applications and components for which alternatives do not exist, the PFAS containing material can be recollected after its design lifetime by the equipment manufacturer in a take back program. The ultimate responsibilities of processing and quality requirements of the recollected and recycled PFAS are not yet clear as this industrial ecology still needs to develop. A positive regulatory framework can stimulate the growth of these recycle hubs and take back programs.
- CONTROLLED DISPOSAL: If recycle options are exhausted for a PFAS containing component, a correct disposal technique should be chosen allowing complete remineralization of the involved polymer preferentially with energy recuperation. A great example of remineralization is the conversion of PFAS to Calcium fluorite in a controlled incineration plant. According to scientific literature, the incineration of PTFE shows no significant generation of harmful low molecular PFAS. Thereby PTFE is decomposed into Carbon dioxide and HF. HF is then converted in the filter system into CaF_2 (fluorspar). A comprehensive article was published in 2019 in Chemosphere, Volume 226, page 898ff. This article is provided as attachment to this consultation. More information is available at the Institute of Technology in Karlsruhe **[5]**. Following this approach, PTFE can be safely disposed

by incineration at the end of the product life-time. However, recycling of PTFE should be always the 1st choice (if applicable for the specific product). A method of PTFE recycling was already invented by mechanical regrinding single-graded waste and re-use of the resulting powder when creating new sealing material.
Additional developments are still expected from environmental technology (advanced oxidizing processes, plasma processes…) to enter the market specifically to deal with PFAS. As compressor manufacturers, it is unclear to date which technology will be the best available technology. It should be emphasized that this route of controlled disposal is the last resort. As soon as design for end of life considerations get more widespread the effective quantities ending up in controlled disposal are expected to decrease over time.

On behalf of PN18

Michael Schulz (Chairman)

Andreas Brand (Secretary)

6 Additional References:

1 https://hydrogeneurope.eu/wp-content/uploads/2023/02/Hydrogen-Europe-position-paper-on-PFAS-ban_v12_FINAL.pdf

2 https://ehb.eu/files/downloads/ehb-report-220428-17h00-interactive-1.pdf

3 https://www.esaknowledgebase.com/wp-content/uploads/2022/03/ESA-Position-Statement-on-proposed-PFAS-regulation-March-2022-1.pdf

4 https://www.fpp4eu.eu/wp-content/uploads/2023/04/FPP4EU-Position-Paper-April-2023-final-1.pdf

5 https://www.kit.edu/