Impact on SMEs of a restriction on fluoropolymers

The European Small Business Alliance for Fluoropolymers comments on the ANNEX XV RESTRICTION REPORT on per- and polyfluoroalkyl substances (PFASs)

September 2023

Executive Summary:

The European Small Business Alliance for Fluoropolymers (ESBAF) is a newly formed ad-hoc coalition of European SMEs that safely utilize fluoropolymers across diverse, complex, and critical supply chains and for various standard chemical processes. ESBAF counts nine SMEs among its membership, covering various stages of the manufacturing supply chain, all of whom have only recently been alerted of the potential impacts of the PFAS restriction proposal. While recognizing the necessity of addressing risks from certain PFAS concerns, ESBAF emphasizes the distinctive nature of fluoropolymers compared to other PFAS, their demonstrated benign hazard profile, the lack of recognised alternatives in high-performance and strategic applications, and the severe consequences the restriction may have on SMEs. Ultimately, ESBAF calls for fluoropolymers to be excluded from the scope of the proposed restriction.

SMEs play a vital role in driving economic growth, fostering innovation, and creating employment opportunities in Europe. They form the backbone of European society, contributing significantly to the development and prosperity of the EU. As the EU pursues its industrial goals and strategic autonomy, the delicate balance between independent industrial capabilities, innovation, and SME viability becomes paramount. In a recent report, the European Commission underscores the unprecedented challenges faced by SMEs amidst economic uncertainty.[1] In this context, the proposed REACH restriction on Per- and Polyfluoroalkyl Substances (PFAS) poses an existential threat to the many SMEs who safely utilize fluoropolymers (such as PTFE, FKM, FFKM, etc.) along various strategic supply chains.

These fluoropolymers, possessing unparalleled properties, serve as the foundation of supply chains in vital sectors such as hydrogen, semiconductors, the food industry, and medical devices, to name a few. While some strategic end uses are benefiting from time-bound derogations under the proposed restriction, the SMEs constituting the intricate and essential remainder of these supply chains have been left in a precarious position. In this paper, ESBAF outlines its key arguments in favour of an exclusion of fluoropolymers from the scope of the impending restriction, to safeguard the vibrancy and resilience of the SMEs that underpin Europe's economic fabric and society more generally.

ESBAF's key messages regarding the proposed restriction dossier are:

- **Fluoropolymers are distinct from other PFAS:** ESBAF recognizes the importance of addressing the risks associated with certain PFAS of concern, but stresses that it is crucial to differentiate between fluoropolymers and other polymeric and nonpolymeric PFAS.[2] Fluoropolymers are high molecular

[1] Di Bella, L., Katsinis, A., & Lagüera-González, J. (2023). *SME Performance Review*. European Commission's Joint Research Centre. Link

[2] Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrative Environmental Assessment and Management, 14*(3), 316-334. doi:10.1002/ieam.4035

weight (typically a number average molecular weight in a range of Da 30000 to 500000 g/mol)[3] polymers with unique properties attributable to the strong C–F bonds, the strongest single bond in organic chemistry[4], making them highly stable. Unlike certain PFAS of concern, fluoropolymers have been extensively studied and proven to be safe for use in their intended applications. In addition, 96% of commercially accessible fluoropolymers conform to the OECD Polymer of Low Concern (PLC) criteria.[5] Finally, given their intrinsic properties, fluoropolymers do not deteriorate during both intended use and exposure to environmental conditions.[6] It is crucial to adopt a differentiated approach to regulating fluoropolymers to ensure a balanced, proportional, and evidence-based regulatory approach.[7,8]

- **There are no viable alternatives for fluoropolymers in many high-performance applications:** Fluoropolymers demonstrate extraordinary qualities that include exceptional resistance to chemicals, heat (up to 325 degrees Celsius continuously), aging, and weathering, along with unique electrical performances.[9,10] These polymers maintain their stability when exposed to hydrocarbons, solvents, acids, bases, and their combinations, which underscores their strong compatibility with various chemicals. The strong C−F bond present in these polymers greatly enhances their remarkable ability to withstand the detrimental effects of both hydrolytic and oxidative factors. This inherent stability, combined with their unique characteristics, leads to exceptional and lasting performances in various critical and strategic applications. Restricting the use of fluoropolymers without viable alternatives would hinder technological advancements, limit product innovation, and compromise the overall competitiveness of European industries. Further, replacing fluoropolymer compounds with lower performing substances may potentially lead to regrettable substitutions from a hazard and sustainability point of view, since the structural properties of fluoropolymers ensure a safe and sustainable use of products / chemical processes.

- **The proposed restriction would have severe consequences for European industries, particularly SMEs:** While certain end-uses have been granted derogations in the proposed restriction dossier, there is a notable absence of consideration for the various comprehensive supply chain for these end-uses. Many SMEs, which are integral to advancing a range of EU objectives, are reliant on fluoropolymers for their operations. Consequently, a ban on fluoropolymers will likely lead to supply chain vulnerabilities impacting the EU's ability to access the fluoropolymers it needs to develop strategic technologies, potentially leading to the erosion of these industries as a whole. Given that SMEs are the backbone of our economy, the potential fallout could result in business closures, job losses, and hindered economic

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[3] Maccone P, Apostolo M, Ajroldi G. Molecular weight distribution of fluorinated polymers with long chain branching. Macromolecules 2000,33,1656-1663.
[4] Atkins. P, Paula. J, 2014, Atkins' Physical Chemistry 10th Edition, Oxford University Press, Oxford, Page 985-986, Table 10C.2a and 10C.2b.
[5] Organisation for Economic Co-operation and Development. (2009). *Data analysis of the identification of correlations between polymer characteristics and potential for health or ecotoxicological concern*. Link
[6] Sales, J., & et al. (2022). Fluoropolymers: The Safe Science That Society Needs. *International Chemical Regulatory and Law Review, 5*(1), 13-17.
[7] OECD. (2009). Data analysis of polymer characteristics. Link
[8] UK Health and Safety Executive. (2023). *Regulatory management options for Poly- and perfluoroalkyl substances (PFAS)*. Link
[9] Zulfiqar, S., & et al. (1994). Study of the thermal degradation of polychlorotrifluoroethylene, poly (vinylidene fluoride) and copolymers of chlorotrifluoroethylene and vinylidene fluoride. *Polymer Degradation and Stability, 43*(3), 423-430. Link
[10] McKeen, L. W. (2014). *The Effect of Long-Term Thermal Exposure on Plastics and Elastomers*. Elsevier. Link

growth. In fact, among our member companies, the majority would be at risk of closure, while the remainder would face extensive restructuring.

- **The restriction as it stands would be impossible to implement for SMEs:** The current proposed restriction presents a significant challenge for SMEs due to the complex and interconnected nature of the supply chains utilizing fluoropolymers. This complexity arises from the involvement of various stakeholders, making it difficult for small businesses to accurately track and classify the diverse end-uses that these products serve. The lack of harmonized classification for PFAS under the CLP Regulation also results in the absence of information transmission along the supply chain (such as through safety data sheets), leading to a time-consuming and often unfeasible analysis of the extent of impact. This situation leaves SMEs struggling to identify specific applications and qualify for potential derogations. The lack of clarity regarding end-use purposes, coupled with uncertainty about derogation eligibility, greatly impedes SMEs' ability to navigate the intricate regulatory landscape.

ESBAF calls on EU regulators to exclude fluoropolymers from the scope of the proposed restriction on PFAS. While it is essential to address potential risks associated with certain PFAS of concern, it is equally important to consider the supply chain complexities and the indispensable role of SMEs in driving innovation and economic growth. By excluding fluoropolymers from the proposed restriction, European SMEs will be able to continue their contributions to the wealth of the society, economic growth, technological advancement, and job creation.

About ESBAF:
The European Small Business Alliance for Fluoropolymers (ESBAF) is a newly formed ad-hoc coalition of SMEs that utilize fluoropolymers across diverse and complex European supply chains and standard chemical processes. ESBAF counts nine SMEs among its membership, covering various stages of the manufacturing supply chain, all of whom have only recently been alerted of the potential impacts of the PFAS restriction proposal and who are underrepresented in Brussels.

Case study: supply chain impacts of a ban on FFKM

Introduction

The Netherlands, Germany, Denmark, Norway, and Sweden submitted a restriction dossier on per- and polyfluoroalkyl substances (PFAS) to the European Chemicals Agency (ECHA). The main objective of this effort is to restrict the manufacturing, selling, and importing of about 10,000 chemical compounds, including fluoropolymers. This case study investigates the scenario of a ban on a widely used fluoropolymer, Perfluoroelastomers (FFKM), aiming to explain the impact of such restriction on standard industrial processes found in various supply chains.

What is FFKM?

FFKMs are advanced synthetic elastomers that consist of fully fluorinated compounds polymeric component. Monomers used within these polymers are: tetrafluoroethylene (TFE), a perfluoro alkyl vinyl ether (PAVE), and a fully fluorinated cure site monomer (such as 1-Iodo-trifluoro-ethene). FFKM elastomers are notable for their remarkable chemical and thermal resistance to both chemicals and high temperatures, their outstanding ability to repel resist gas and liquid permeation, and their capacity to withstand the effects of weather and ozone.[11,12,13] Operating effectively within a wide temperature range of -45 to 330 °C, FFKM elastomers offer versatile performance attributes and are widely used in industrial applications, such as critical sealing solutions for the aerospace, pharmaceutical, medical, chemical processing, and semiconductor sectors.[14,15]

The Integrated Supply Chain for FFKM: Ensuring Quality and Performance

Compounder:

Compounders buy FFKM polymers from major specialty chemical producers. They combine these base polymers together with additives, such as fillers, curatives, and pigments to produce a carefully engineered product that provides desired properties tailored for specific applications.

Manufacturers of Seals and Gaskets:

FFKM compounds are used by manufacturers to produce a broad range of seals and gaskets, which are essential components for creating leak-proof and durable connections of mechanical parts across many industries. During the manufacturing process, the FFKM undergoes vulcanization, an irreversible chemical process that enhances its properties by crosslinking/vulcanizing the polymeric chains into a 3-dimensional structure with high molecular weight. This process determines some of the article's final chemical, physical, mechanical, and dimensional properties. The most common process to achieve this, uses a tool and press. By applying pressure and temperature the compound achieves the desired shape and necessary properties.

Distributors:

Distributors purchase these FFKM seals and gaskets from manufacturers to place them on the market. They play a critical role in ensuring that the right products reach the right applications, based on specific requirements.

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[11] Drobny JG. 2006. Fluoroplastics. Shropshire (UK): Rapra Technology. p 12.
[12] Greene-Tweed. (2021a). FKM versus FFKM–A comparison of properties. https://live-greene-tweed.pantheonsite.io/wp-content/uploads/2020/04/FKM-vs-FFKM-Properties-Comparison-R3.pdf
[13] Green-Tweed. (2021b). FKM vs. FFKM. https://www.gtweed.com/materials/fkm-vs-ffkm/
[14] Atkinson, S. (2018). Essential high-purity sealing materials for semiconductormanufacturing. Sealing Technology,7,5–7. https://doi.org/10.1016/S1350-4789(18)30284-8
[15] Marshall, J. 2017. Kalrez®-type perfluoroelastomers—Synthesis, propertiesand applications. In J. Scheir (Ed.), Modernfluoropolymers(pp. 349–358). John Wiley and Sons.

Applications in Pumps and Equipment:
These FFKM seals and gaskets find their way into various industrial equipment, such as pumps, or are first integrated into mechanical seals which will then be used further in the supply chain. Pumps, which are used for fluid transport, require seals that can withstand aggressive chemicals and maintain their integrity over time. The properties of FFKMs ensure reliable performance in these harsh environments.

Impact on End-Use Equipment:
The pumps, equipped with FFKM seals are integrated into larger systems that produce specific end-use products. End-use applications may include pharmaceuticals, chemicals, medical devices, food and beverage, semiconductors, and green hydrogen. The integration into many different end-uses showcases the diverse role that FFKMs plays in supporting critical and strategic industries.

Considerations:
The above provides a simplified depiction of the fluoropolymer supply chain reduced to only its essential steps and exemplifies its complexity and deep level of integration within industrial processes. The diverse applications of FFKMs increase the number and complexity of supply chains. Often, stakeholders, especially those early in the supply chain, will not even know the final use of their FFKM product.

To shed more light on the impacts a ban on FFKMs would mean to modern day society, the following case study illustrates what would happen if FFKMs would be replaced by a non-fluorinated elastomer.

<u>The example of the Centrifugal Pump and non-fluorinated O-Rings</u>

A pump manufacturer receives a request for a centrifugal pump. Centrifugal pumps are used in a variety of industrial processes, such as for the production of semiconductors or the electrolysis of green hydrogen. All applications demand high-level precision engineering and require robust components to ensure safe and efficient production.

A centrifugal pump is a mechanical device that uses a rotating impeller to create a flow of fluid by converting rotational energy into kinetic energy, resulting in increased pressure and movement. A centrifugal pump needs seals to prevent fluid leakage at points where the rotating shaft meets the pump casing. These seals maintain fluid containment and contribute to efficient pump performance by reducing internal recirculation.

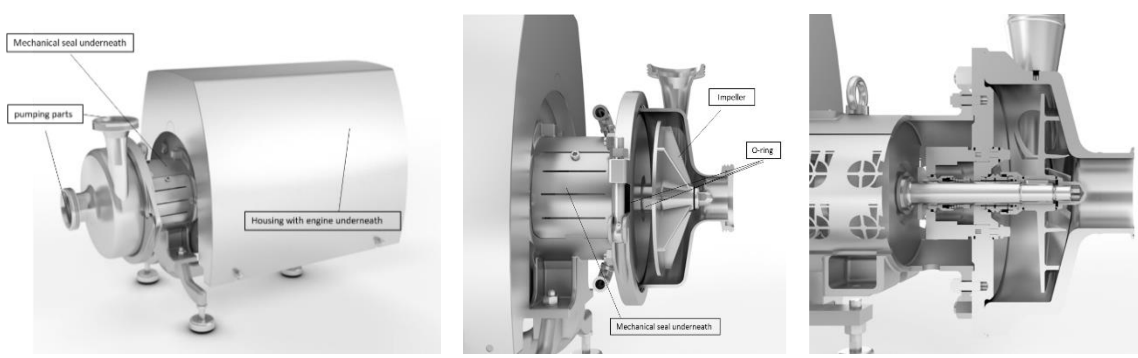

Figure 1: Centrifugal pump

In order to ensure that the seals provide the correct technical performance characteristics, the pumps manufacturer engages with a distributor and a mechanicals seals manufacturer. Mechanical seals consist of a stationary sealing face and a rotating sealing face, while incorporating an elastomer seal like an O-ring to create a secure barrier between stationary and rotating components. For this elastomeric part the mechanical seal manufacturer also engages with the distributor who recommends using FFKM seals. For all applications where a particularly aggressive medium is pumped at elevated temperature, the seals require a very high chemical and thermal resistance. (For the purpose of this case study, the example sheds light on FFKM parts, specifically O-rings. However, centrifugal pumps also require rubber-based form parts and integrate other fluoropolymers, such as polyvinylidene fluoride (PVDF) and Polytetrafluoroethylene (PTFE)).

FFKMs provide the required thermal and chemical characteristics. The excellent thermal resistance allows the material to seal for a significant period, this can be evidenced by the low compression set (see Figure 2 below). A compression set is the term used to describe the phenomenon wherein a material undergoes permanent deformation and loss of its ability to maintain a seal after being subjected to compression or maintained in a compressed state over an extended period. This metric serves as an indicator of the material's ability maintain a seal effectively, where a lower figure indicates a longer seal life. The below graph shows the compression set of an FFKM against the compression set of a “high temperature” silicone and HNBR. Figure 2 visualises that the compression set of an FFKM is significantly lower than that of a “high temperature” silicone or a HNBR. It indicates a minimum increase of life of 500 times when using an FFKM over non PFAS alternatives.

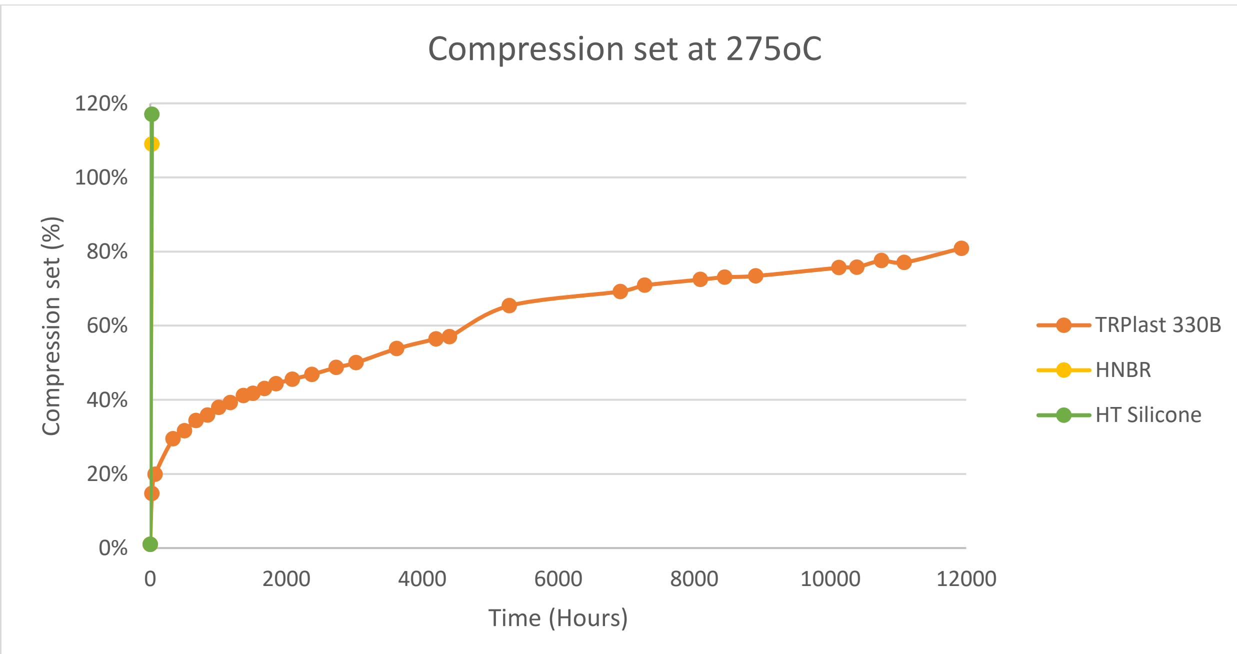

Figure 2: Compression set of an FFKM against the compression set of a “high temperature” silicone and HNBR (data generated by one ESBAF member)

In order to match the right compound for the application, the distributor uses a so-called ‘chemical resistance guide. A chemical resistance guide is a compilation of materials and their corresponding reactions to different chemicals. It provides valuable information about the chemical resistance of compounds when exposed to specific chemical agents through a scale from A (suitable) to D (not suitable). Annex A provides an example of such a list showcasing that in most mediums FFKMs perform best (A).

The distributor requests the required FFKM parts at a seal manufacturer who uses the correct FFKM compound and produces O-rings with the desired dimension, hardness, and physical properties. These products are integrated into the centrifugal pump. The integrated efforts of stakeholders in the fluoropolymer supply chain culminate in a reliable, safe, and environmentally conscious production process.

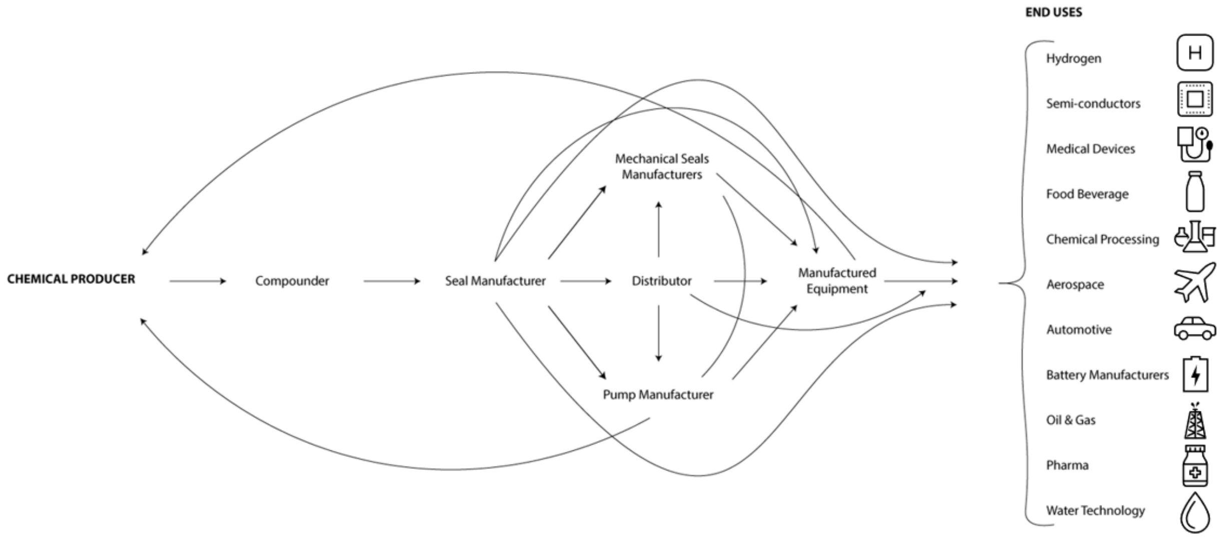

Figure 3: Simplified visualisation of the fluoropolymer supply chain, including a selected number of end-uses

What would happen in the event of a ban on FFKMs?

As explained previously, fluoropolymers display strong thermal and chemical resistance. If FFKMs were to be banned, the FFKM parts in the pump would have to be substituted by non-fluorinated elastomer parts. This substitution would have several important and detrimental impacts.

(Please note that this analysis focuses solely on the sealing parts of a pump and doesn't account for the main parts, which also require resistant materials such as FFKMs and/or other fluoropolymers.)

Technical Performance would be compromised:
Using a non-fluorinated O-ring in a medium that requires high chemical resistance would result in deterioration of the seal or a significantly reduced seal life. Using a non-fluorinated elastomer in an aggressive medium can typically cause 3 effects:

1. Seal swelling, this can cause several failures such as increased permeation of chemicals, seal breakdown which then combines with process fluid, splitting caused by excessive swelling which compromises the seal. the photo below shows a typical swollen elastomer, where a tear has formed that caused fluid leakage.

Figure 4: Swelling of a seal with low chemical resistance (e.g. non-fluorinated) used in aggressive medium (Illustration from ESBAF members)

2. Polymer degradation, this can cause cracking or softening and reduces the ability for a material to maintain a seal significantly, which in turn reduces service life. This can not only cause fluid leakage but can cause contaminants to pass into process fluids. The below photo shows a typical example of a degraded material.

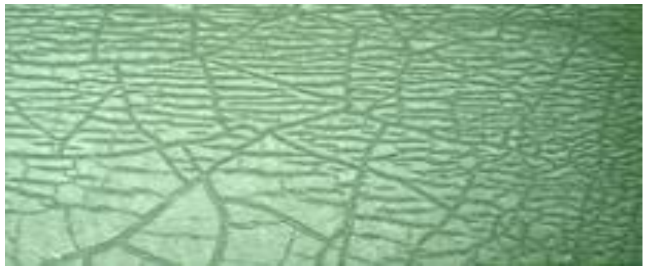

Figure 5: Polymer degradation (Illustration from ESBAF members)

3. Polymer dissolution, this can occur where the process fluid dissolves the polymer itself. This physically removes seal material, and quickly causes seal failure.

Figure 6: Polymer dissolution (Illustration from ESBAF members)

From a thermal resistance perspective, the non-fluorinated elastomer can only be used in processes that occur up to 200 degrees Celsius. Every process at higher temperatures also results in material failure up to degradation and therefore loss of sealing integrity. Processes at a higher temperature will lead to a significantly reduced service life and hence time until leakage for non PFAS materials.

Risk to the environment would increase substantially:
The decreased chemical and thermal resistance of O-rings due to using non-fluorinated materials can have significant environmental implications. The accelerated breakdown of O-rings necessitating immediate replacements not only undermines circularity goals by generating more waste and resource consumption but also leads to reduced operational efficiency with higher energy consumption for maintenance and replacement processes. Moreover, the heightened risk of leaks due to compromised O-ring durability can result in emissions of harmful substances, potentially posing severe environmental risks and contamination of ecosystems.

Workers' Health and Safety would be at risk:
The diminished thermal resistance and chemical resistance of using non-fluorinated elastomers pose significant hazards to worker safety. The heightened potential for leaks and the risk of swelling-induced pressure compromises the structural integrity of applications, potentially leading to total failures. Such failures severely jeopardise workers health and safety by e.g., exposing them to hazardous substances.

Conclusion: Ensuring Resilience, Sustainability, and Safety in the Fluoropolymer Supply Chain

The FFKM supply chain highlights the intricate interplay of various stakeholders, from chemical companies to end-users. In addition, the example of a centrifugal pump with and without FFKMs show that the fluoropolymer's unique properties are vital for maintaining performance, sustainability, and safety across the supply chain. Any restrictions on FFKM would disrupt this supply chain, potentially leading to negative impacts on equipment reliability, environmental protection, worker safety, and standard industrial processes.

Annex A: Chemical resistance guide

Medium	NR, IR	SBR, BR	IIR	EPDM, EPM	NBR	CR	SI, VMQ	FFKM
Acetic Anhydride	B	B	B	B	C	B	C	A
Acetyl Chloride	D	D	D	D	D	D	C	A
Acrlylonitrile	D	D	D	D	D	D	D	A
Alkazene (Dibromoethylbenzene)	D	D	D	D	D	D	D	A
Amyl Acetate (Banana Oil)	D	D	C	C	D	D	D	A
Amyl Chloronapthalene	D	D	D	D	D	D	D	A
Amyl Napthalene	D	D	D	D	D	D	D	A
Aniline Hydrochloride	B	D	B	B	B	D	D	A
Ansul Ether (Anesthetics)	D	D	C	C	C	D	D	A
Aqua Regia	D	D	D	C	D	D	D	A
Aroclor, 1248	D	D	C	C	C	D	B	A
Aroclor, 1254	D	D	D	C	D	D	C	A
Askarel	D	D	D	D	B	D	D	A
Asphalt	D	D	D	D	B	B	D	A
Banana Oil (Amyl Acetate)	D	D	C	C	D	D	D	A
Benzene	D	D	D	D	D	D	D	A
(Nitrobenzine) (Pet Ether)	D	D	D	C	D	B	D	A
Benzoic Acid	D	D	D	C	C	D	C	A
Benzoyl Chloride	D	D	D	D	D	D	*	A
Benzyl Benzoate	D	D	B	B	D	D	*	A
Benzyl Chloride	D	D	D	D	D	D	D	A
(Phenylbenzene)	D	D	D	D	D	D	D	A
Bromine-Anydrous	D	D	D	D	D	D	D	A
Bromine Trifluoride	D	D	D	D	D	D	D	A
Bromine Water	D	D	C	B	D	D	D	A
Bromobenzene	D	D	D	D	D	D	D	A
Butadiene	D	D	D	C	D	D	D	A
Butyl Acetate	D	D	C	C	D	D	D	A
Butyl Acrylate	D	D	D	D	D	D	*	A
Butyl Amine	D	D	C	B	C	D	D	A
Butyl Benzoate	C	B	B	B	D	D	*	A
Butyl Oleate	D	D	B	B	D	D	*	A
Butyl Stearate	D	D	C	C	B	D	*	A
Butylene	D	D	D	D	B	C	D	A
Butyraldehyde	D	D	B	B	D	C	D	A
Carbamate	D	D	B	B	C	B	*	A
Carbitol	B	B	B	B	B	B	B	A
Carbolic Acid (Phenol)	D	D	B	B	D	C	D	A
Carbon Bisulfide	D	D	D	D	C	D	D	A
Carbon Tetrachloride	D	D	D	D	C	D	D	A
Cellosolve	D	D	B	B	D	D	D	A
Cellosolve Acetate	D	D	B	B	D	D	D	A
Chlorine (Dry)	D	D	D	D	D	C	D	A
Chlorine (Wet)	D	D	C	C	D	C	D	A
Chlorine Dioxide	D	D	C	C	D	D	*	A
Chlorine Trifluoride	D	D	D	D	D	D	D	A
Cholorobenzene	D	D	D	D	D	D	D	A
Chlorobromomethane	D	D	B	B	D	D	D	A
Chlorobutadiene	D	D	D	D	D	D	D	A
Chlorododecane	D	D	D	D	D	D	D	A
Chloroform	D	D	D	D	D	D	D	A
O-Chloronapthalene	D	D	D	D	D	D	D	A
1-Chloro-1-Nitro Ethane	D	D	D	D	D	D	D	A
Chlorosulfonic Acid	D	D	D	D	D	D	D	A
Chlorotoluene	D	D	D	D	D	D	D	A
Chrome Plating Solutions	D	D	B	B	D	D	B	A
Chromic Acid	D	D	C	C	D	C	C	A
Coke Oven Gas	D	D	D	D	D	D	B	A
Cresol	D	D	D	D	D	C	D	A
Cresylic Acid	D	D	D	D	D	C	D	A
Cumene	D	D	D	D	D	D	D	A

Cyclohexanone	D	D	B	B	D	D	D	A
P-Cymene	D	D	D	D	D	D	D	A
Decalin	D	D	D	D	D	D	D	A
Dibenzyl Ether	D	D	B	B	D	C	*	A
Dibenzyl Sebecate	D	D	B	B	D	D	C	A
Dibromoethylbenzene	D	D	D	D	D	D	D	A
Dibutyl Amine	D	D	D	C	D	D	C	A
Dibutyl Ether	D	D	C	C	D	C	D	A
Dibutyl Phthalate	D	D	C	B	D	D	B	A
Dibutyl Sebecate	D	D	B	B	D	D	B	A
O-Dichlorobenzene	D	D	D	D	D	D	D	A
Dichloro-Isopropyl Ether	D	D	D	C	D	D	D	A
Dicyclohexylamine	D	D	D	D	C	D		A
Diethylamine	B	B	B	B	B	B	B	A
Diethyl Benzene	D	D	D	D	D	D	D	A
Diethyl Ether	D	D	D	D	D	C	D	A
Diethyl Sebecate	D	D	B	B	B	D	B	A
Diisobutylene	D	D	D	D	B	D	D	A
Diisopropyl Benzene	D	D	D	D	D	D	*	A
Diisopropylidene Acetone (Phorone)	D	D	C	C	D	D	D	A
Dimethyl Aniline (Xylidine)	C	C	C	B	C	C	D	A
Dimethyl Formamide	D	D	B	B	B	C	B	A
Dimethyl Phthalate	D	D	B	B	D	D	*	A
Dinitrotoluene	D	D	D	D	D	D	D	A
Dioctyl Phtalate	D	D	B	B	C	D	C	A
Dioctyl Sebecate	D	D	B	B	D	D	C	A
Dioxane	D	D	B	B	D	D	D	A
Dioxolane	D	D	C	B	D	D	D	A
Dipentene	D	D	D	D	B	D	D	A
(Phenylbenzene)	D	D	D	D	D	D	D	A
Diphenyl Oxides	D	D	D	D	D	D	C	A
Dowtherm Oil	D	D	D	D	D	D	C	A
Dry Cleaning Fluids	D	D	D	D	C	D	D	A
Epichlorohydrin	D	D	B	B	D	D	D	A
Ethanolamine	B	B	B	B	B	B	B	A
Ethyl Acetate	D	D	B	B	D	C	B	A
Ethyl Acetoacetate	C	C	B	B	D	C	B	A
Ethyl Acrylate	D	D	B	B	D	D	B	A
Ethyl Benzene	D	D	D	D	D	D	D	A
Ethyl Cellosolve	D	D	D	D	D	D	D	A
Ethyl Cellulose	B	B	B	B	B	B	C	A
Ethyl Chlorocarbonate	D	D	C	B	D	D	D	A
Ethyl Chloroformate	D	D	C	B	D	D	D	A
Ethyl Ether	D	D	C	C	C	C	D	A
Ethyl Formate	D	D	B	B	D	B	*	A
Ethyl Mercaptan	D	D	D	C	D	C	C	A
Ethyl Pentachlorobenzene	D	D	D	D	D	D	D	A
Ethylene Chloride	D	D	C	C	D	D	D	A
Ethylene Chlorohydrin	B	B	B	B	D	B	C	A
Ethylene Dichloride	D	D	C	C	D	D	D	A
Ethylene Oxide	D	D	C	C	D	D	D	A
Ethylene Trichloride	D	D	C	C	D	D	D	A
Fatty Acids	D	D	C	C	B	B	C	A
Fluorobenzene	D	D	D	D	D	D	D	A
Freon 21	D	D	D	D	D	D	D	A
Furan, Furfuran	D	D	D	C	D	D	*	A
Furfural	D	D	B	B	D	C	D	A
Gasoline	D	D	D	D	B	C	D	A
Glauber's Salt (Aqueous)	B	D	B	B	D	B	*	A
Halowax Oil	D	D	D	D	D	D	D	A
N-Hexene-1	D	D	D	D	B	B	D	A
Hydrochloric Acid (Hot) 37%	D	D	C	C	D	D	D	A
Hydrofluoric Acid (Conc.) Cold	D	D	C	C	D	D	D	A

Hydrofluoric Acid (Conc.) Hot	D	D	D	D	D	D	D	A
Hydrofluoric Acid- Anhydrous	D	D	C	C	D	D	D	A
Hydrogen Peroxide (90%)	D	D	C	B	D	D	B	A
Hydroquinone	B	D	B	B	C	D	*	A
Hypochlorous Acid	B	D	B	B	D	D	*	A
Iodine Pentafluoride	D	D	D	D	D	D	D	A
Iodoform	D	D	D	D	*	D	*	A
Isophorone	D	D	C	C	D	D	D	A
Isopropyl Acetate	D	D	B	B	D	D	D	A
Isopropyl Chloride	D	D	D	D	D	D	D	A
Isopropyl Ether	D	D	D	D	B	C	D	A
Lacquers	D	D	D	D	D	D	D	A
Lacquer Solvents	D	D	D	D	D	D	D	A
Lactic Acid (Hot)	D	D	D	D	D	D	B	A
Lavendar Oil	D	D	D	D	B	D	D	A
Linoleic Acid	D	D	D	D	B	D	B	A
Maleic Acid	C	C	B	B	D	C	*	A
Malic Acid	C	C	B	B	D	C	*	A
Mesityl Oxide	D	D	B	B	D	D	D	A
Methyl Acrylate	D	D	B	B	D	B	D	A
Methylacrylic Acid	D	D	B	B	D	B	D	A
Methyl Bromide	D	D	D	D	B	D	*	A
Methyl Cellosolve	D	D	B	B	C	C	D	A
Methyl Chloride	D	D	C	C	D	D	D	A
Methyl Cyclopentane	D	D	D	D	D	D	D	A
Methylene Chloride	D	D	D	C	D	D	D	A
Methyl Formate	D	D	B	B	D	B	*	A
Methyl Isobutyl Ketone	D	D	C	B	D	D	D	A
Methyl Methacrylate	D	D	D	C	D	D	D	A
Methyl Oleate	D	D	B	B	D	D	*	A
Methyl Salicylate	C	C	B	B	D	D	*	A
Monochlorobenzene	D	D	D	D	D	D	D	A
Monomethyl Aniline	D	D	B	B	D	D	*	A
Naphtha	D	D	D	D	B	C	D	A
Naphthalene	D	D	D	D	D	D	D	A
Naphthalenic Acid	D	D	D	D	B	D	D	A
Neville Acid	D	D	B	B	D	D	D	A
Nitric Acid (Conc.)	D	D	D	D	D	D	D	A
Nitric Acid (Dilute)	D	D	B	B	D	B	B	A
Nitric Acid-Red Fuming	D	D	D	D	D	D	D	A
Nitroethane	B	B	B	B	D	C	D	A
Nitromethane	B	B	B	B	D	B	D	A
Octachlorotoluene	D	D	D	D	D	D	D	A
N-Octane	D	D	D	D	B	B	D	A
Oleum Spirits	D	D	D	D	B	C	D	A
O-Dichlorobenzene	D	D	D	D	D	D	D	A
Oxygen-(200-400oF)	D	D	D	C	D	D	B	A
Paint Thinner, Duco	D	D	D	D	D	D	D	A
Perchloric Acid	D	D	B	B	D	B	D	A
Perchloroethylene	D	D	D	D	B	D	D	A
Petroleum-Above 250oF	D	D	D	D	D	B	D	A
Phenol (Carbolic Acid)	D	*	B	B	D	C	D	A
(Diphenyl)	D	D	D	D	D	D	D	A
Phenyl Ethyl Ether	D	D	D	D	D	D	D	A
Phorone (Diisopropylidene Acetone)	D	D	C	C	D	D	D	A
Pickling Solution	D	D	C	C	D	D	D	A
Pinene	D	D	D	D	B	C	D	A
Pine Oil	D	D	D	D	D	D	D	A
Piperidine	D	D	D	D	D	D	D	A
i-Propyl Acetate	D	D	B	B	D	D	D	A
n-Propyl Acetate	D	D	B	B	D	D	D	A
Propyl Nitrate	D	D	B	B	D	D	D	A
Propylene	D	D	D	D	D	D	D	A

Propylene Oxide	D	D	B	B	D	D	D	A
Pydraul, 230E, 312C, 540C	D	D	D	D	D	D	D	A
Pyridine	D	D	B	B	D	D	D	A
Pyroligneous Acid	D	D	B	B	D	B	*	A
Pyrrole	C	C	D	C	D	D	B	A
Radiation	C	C	D	B	C	B	C	A
Steam Over 300oF	D	D	D	C	D	D	D	A
Stearic Acid	B	B	B	B	B	B	B	A
Styrene	D	D	D	D	D	D	D	A
Sulfite Liquors	B	B	B	B	B	B	D	A
Sulfur Chloride (Aqueous)	D	D	D	D	C	C	C	A
Sulfur Trioxide	B	B	B	B	D	D	B	A
Sulfuric Acid (Dilute)	C	C	B	B	C	B	D	A
Sulfuric Acid (conc.)	D	D	D	C	D	D	D	A
Sulfuric Acid (20% Oleum)	D	D	D	D	D	D	D	A
Sulfurous Acid	B	B	B	B	B	B	D	A
Tar, Bitruminous	D	D	C	C	B	C	B	A
Terpineol	D	D	C	C	B	D	*	A
Tertiary Butyl Alcohol	B	B	B	B	B	B	B	A
Tertiary Butyl Catechol	D	B	B	B	D	B	*	A
Tertiary Butyl Mercaptan	D	D	D	D	D	D	D	A
Tetrabromoethane	D	D	D	D	D	D	D	A
Tetrabromomethane	D	D	D	D	D	D	D	A
Tetrachloroethylene	D	D	D	D	D	D	D	A
Tetrahydrofuran	D	D	C	C	D	D	D	A
Tetralin	D	D	D	D	D	D	D	A
Thionyl Chloride	D	D	D	C	D	D	*	A
Titanium Tetrachloride	D	D	D	D	B	D	D	A
Toluene	D	D	D	D	D	D	D	A
Toluene Diisocyanate	D	D	B	B	D	D	D	A
Tributyl Mercaptan	D	D	D	D	D	D	D	A
Tributyl Phosphate	B	D	B	B	D	D	D	A
Trichloroacetic Acid	C	B	B	B	B	D	*	A
Trichloroethane	D	D	D	D	D	D	D	A
Trichloroethylene	D	D	D	D	D	D	D	A
Triethyl Aluminum	D	D	C	C	D	D	*	A
Triethyl Borane	D	D	C	C	D	D	*	A
Trinitrotoluene	D	D	D	D	D	B	*	A
Turbine Oil	D	D	D	D	B	D	D	A
Varnish	D	D	D	D	B	D	D	A
Vinyl Chloride	D	D	D	D	D	D	*	A
White Pine Oil	D	D	D	D	B	D	D	A
Xylene	D	D	D	D	D	D	D	A
Xylidine (Di-methyl Aniline)	C	C	C	B	C	C	D	A