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Stacked gaskets performance in an electrolyzer

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Electrolyzer gaskets operate within narrow mechanical, dimensional and chemical design windows. This paper examines sealing as a stack-level engineering problem rather than an isolated material-selection task. Experimental results for expanded and restructured PTFE show that creep relaxation can increase markedly when multiple gaskets are assembled in series. The effects of gasket stress, material intrusion, formulation-dependent chemical compatibility and load retention are discussed. These findings are combined with results for two thin PTFE materials developed for PEM/AEM applications. The study shows that reliable electrolyzer sealing requires coordinated consideration of sealability, retained stress, geometry, material formulation and the stack clamping system.

1 Introduction

Water electrolysis is a central technology for producing hydrogen using electrical energy. In an electrolyzer, water is split into hydrogen and oxygen in a series of electrochemical cells. The performance of the complete system depends on the interaction of electrodes, membranes, cell frames, bipolar or separator plates and the sealing system. While the electrochemical components receive considerable attention, the gasket is frequently treated as a comparatively simple mechanical component. In practice, its behavior can directly influence integrity, gas purity, assembly, maintenance requirements and the usable mechanical design window of the stack [1].

Electrolyzer gaskets perform several functions simultaneously. They must prevent external leakage, limit internal cross-leakage between process passages and the anodic and cathodic compartments, maintain pressure and provide electrical insulation where required. At the same time, the gasket must withstand the compressive load imposed during stack assembly without excessive creep or intrusion into flow channels. Because an electrolyzer contains many cells, these requirements are repeated over numerous sealing interfaces rather than being limited to a single flange joint [1].

This repeated configuration is important. Conventional gasket characterization such as DIN EN 13555 provides valuable parameters for sealability and creep-relaxation behavior of individual gasket specimens [3]. Experimental work with stacked PTFE gaskets, however, shows that the mechanical response of a multi-gasket assembly can differ significantly from that of a single gasket [1]. The objective of this paper is therefore to consider electrolyzer sealing from a system perspective. Four interrelated requirements are examined: tightness at the available gasket stress, retention of gasket stress during operation, dimensional stability including resistance to intrusion, and compatibility of the complete gasket formulation with the process environment.

2 Sealing requirements in electrolyzer stacks

2.1 Application-dependent requirements

Alkaline electrolyzers (AEL) and proton exchange membrane (PEM) electrolyzers impose different boundary conditions on the gasket. AEL systems commonly use an aqueous potassium hydroxide electrolyte. The sealing material must therefore be assessed not only for hydrogen and oxygen tightness but also for chemical compatibility with the alkaline medium. Long-term creep behavior and resistance to material flow are also relevant because many sealing interfaces may remain continuously compressed for extended operating periods [1].

PEM electrolyzers use a solid polymer electrolyte and are characterized by compact stack designs. The available bolt load and the allowable deformation of stack components can limit the gasket stress that can be applied. Consequently, a gasket that reaches low leakage only at high surface pressure may be unsuitable even if its intrinsic chemical resistance is excellent. Thin gasket geometries and narrow thickness tolerances also become increasingly important because dimensional deviations accumulate through a multi-cell stack [2].

AEM electrolyzers create another design space. The supplied development article identifies the same trend toward thin PTFE gaskets capable of sealing at low surface pressure for PEM and AEM systems [2]. Specific chemical compatibility and operating conditions nevertheless have to be established for each design before material suitability is concluded.

2.2 The gasket as part of the mechanical stack

A useful way to describe an electrolyzer gasket is not as an isolated sealing element but as a compliant component within a mechanically coupled stack. Initial compression establishes contact and closes leakage paths. Subsequent viscoelastic deformation reduces gasket thickness and can reduce the retained surface pressure. Thermal expansion of metallic components, vibration and operating transients can further change the load acting on the gasket. Load-retention devices such as spring washers can therefore become part of the sealing concept rather than an accessory to it [1], [2].

This system view also explains why gasket thickness, compressibility and manufacturing tolerance matter beyond dimensional fit. If every sealing interface changes thickness during installation or operation, the accumulated movement across tens or hundreds of interfaces can be significant. The gasket material must consequently be selected together with the stack clamping concept, installation procedure and available elastic reserve.

2.3 Limitations of single-gasket characterization

EN 13555 defines gasket parameters relevant to bolted flange-joint design, including the creep-relaxation factor PQR [3]. In the referenced experimental study, PQR was used as a practical measure of retained gasket stress. Tests on a hydraulic press showed that, for both restructured PTFE and expanded PTFE, PQR generally decreased as the number of gaskets arranged in series increased from one to four [1].

The effect became more pronounced in the dedicated electrolyzer test rig shown in Figure 1. One hundred gaskets of 1.5 mm thickness were installed at approximately 30 MPa and monitored for 100 h. The restructured PTFE rPTFE-B1 retained 23.56 MPa after 100 h, corresponding to a PQR of 0.769, whereas ePTFE retained 17.32 MPa, corresponding to a PQR of 0.583. After four hours, the stack PQR values were 0.838 and 0.673, respectively [1].

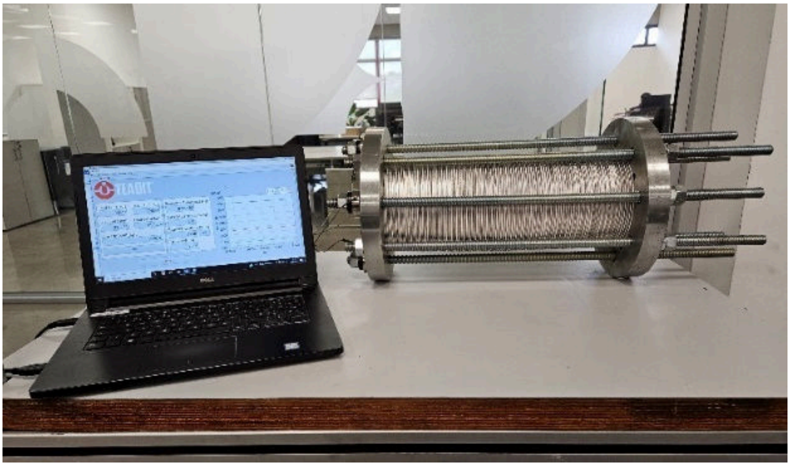

Figure 1: Dedicated electrolyzer test rig used to investigate gasket stress retention in a stacked configuration [1].

Table 1: Stress retention in the 100-gasket electrolyzer test rig at room temperature [1]

Material	**Initial stress [MPa]**	**Stress after 4 h [MPa]**	**Stress after 100 h [MPa]**	**PQR after 100 h**
rPTFE-B1	30.645	25.669	23.557	0.769
ePTFE	29.724	20.008	17.323	0.583

For comparison, the single-gasket room-temperature PQR values reported for the same material families were 0.959 for rPTFE-B1 and 0.956 for ePTFE. The difference demonstrates that a material parameter obtained from a single gasket does not, by itself, reproduce the relaxation behavior of a long compliant stack [1]. This does not invalidate DIN EN 13555 characterization; rather, it shows that standard material data and representative assembly-level validation answer different engineering questions.

An instrumented stress-measuring gasket positioned at the center of the test rig showed agreement between local strain-gauge measurements and external load cells. This supported the assumption that gasket stress was distributed consistently through the tested stack [1]. The observation strengthens the interpretation that the additional relaxation is a stack-mechanics effect rather than simply a local load-distribution anomaly.

2.4 Parameters governing electrolyzer sealing performance

2.4.1 Tightness at low gasket stress

Leakage performance is an obvious requirement, but the relevant question for an electrolyzer is the gasket stress required to achieve that performance. A material that seals effectively only at high surface pressure can impose higher loads on frames, plates and clamping elements. Comparative helium leakage testing of several PTFE gaskets illustrates how strongly material architecture changes the required stress.

For a stated leakage criterion of 1E-2 mg/(s·m), the reported required gasket stress ranged from 12 MPa for rPTFE-B2 to 30 MPa for standard ePTFE. The corresponding compression also varied considerably [1]. These results show that sealability and compressibility cannot be considered independently when defining the stack assembly window.

Table 2: Comparative stress required for a leakage rate of 1E-2 mg/(s·m) [1]

Material	Required stress [MPa]	Reported compression
rPTFE-B1	25	5.2%
rPTFE-B2	12	13.4%
rPTFE-F	19	3.9%
ePTFE	30	62.4%
ePTFE-RGD2	14	14.1%

2.4.2 Stress retention and live loading

Low initial leakage is insufficient if the gasket subsequently loses the surface pressure required to maintain tightness. In the 100-gasket experiment, the largest stress reduction occurred during the early part of the test [1]. This makes the installation and start-up procedure an integral part of the sealing design.

A further evaluation used an actual electrolyzer mock-up with 21 ePTFE gaskets. Without a start-up retorque and without spring washers to compensate relaxation, the study reported a reduction of more than 60% in gasket installation stress after the thermal sequence. The loss could be mitigated by a start-up retorque, while spring elements provide an elastic reserve to compensate subsequent relaxation [1]. The appropriate strategy remains dependent on gasket material and stack design.

2.4.3 Dimensional stability and intrusion

Compression can cause PTFE-based materials to flow radially, as illustrated in Figure 2. In an electrolyzer this may reduce the free cross-section of gas or liquid passages. Intrusion is therefore more than a gasket-durability issue: it can interfere with the hydraulic and gas-flow geometry of the cell. Tests performed for 16 h at 90 °C and 40 MPa showed lower material flow for pre-densified ePTFE than for standard ePTFE. For filled rPTFE, reducing thickness from 2.0 to 1.5 mm also reduced the reported material flow [1].

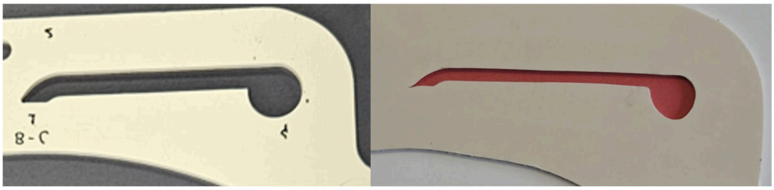

Figure 2: Example of gasket intrusion into an inner flow passage; original geometry (left) and deformed geometry after compression (right) [1].

Dimensional stability also affects assembly. Standard 3 mm ePTFE was reported to compress to approximately 1.127 mm at 30 MPa. In a stack containing many gaskets, repeated compression increases the movement that must be accommodated during tightening. A pre-densified ePTFE variant reduced installation time for 50 gaskets in the test rig from approximately 210 min to 60 min, while also being developed to reduce intrusion [1].

2.4.4 Chemical compatibility of the complete formulation

Chemical compatibility must be assigned to the complete gasket formulation rather than to the PTFE polymer alone. This distinction is particularly important for AEL systems containing concentrated KOH. Although PTFE itself is widely resistant to alkaline media, fillers used to modify mechanical properties can respond differently [1].

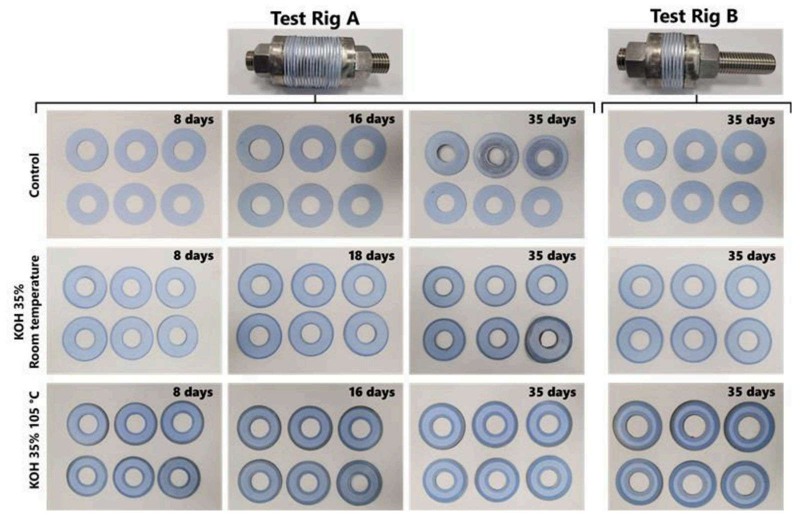

Figure 3: Stacked-gasket test specimens used to evaluate the influence of 35% KOH exposure at room temperature and 105 °C over time [1].

Figure 3 shows specimens from the referenced stacked-gasket compatibility study. In this study, rPTFE-B2 containing micro hollow glass spheres and rPTFE-F containing barite were immersed in 35% KOH solution at 105 °C for up to 35 days using a method based on ASTM F146 [4]. rPTFE-B2 showed increased compressibility and decreased recovery in regions affected by KOH, including in a stacked-gasket test maintained at 30 MPa. Under the same immersion conditions, rPTFE-F showed no significant changes in mass, thickness, compressibility or recovery in the reported tests [1]. The comparison illustrates why compatibility of virgin PTFE cannot automatically be transferred to every filled-PTFE formulation.

2.5 Purpose-designed thin PTFE materials for PEM/AEM stacks

Recent development work has focused on a different design window: very thin gasket sheets with narrow thickness tolerance and high sealability at low gasket stress. The key drivers for PEM/AEM gasket development are limited bolt load, restricted installation space and dimensional consistency across multiple stacked [2]. Two PTFE concepts were developed for this purpose: TF H2, a restructured filled PTFE, and SH H2, a highly compressed pure PTFE.

Table 3: Reported properties of two thin PTFE material concepts [2]

Property	TF H2	SH H2	Design relevance
PTFE concept	Restructured, filled PTFE	Highly compressed pure PTFE	Alternative routes to low-load sealing
Filler	Micro hollow glass spheres	None	Formulation-dependent compatibility
Available thickness	0.35 / 0.50 mm	0.35 / 0.50 mm	Thin stack geometry
Thickness tolerance	+/- 0.05 mm	+/- 0.05 mm	Dimensional consistency
Reported pressure range	Vacuum to 55 bar	Vacuum to 60 bar	Manufacturer material data
Reported temperature range	-268 to +260 °C	-268 to +260 °C	Material capability, not operating range

The broad pressure and temperature ranges in Table 3 are reported material capabilities. They should not be interpreted as an approval, a universal electrolyzer operating envelope or evidence of suitability for every process medium. Application-specific validation remains necessary.

2.5.1 TF H2: restructured PTFE for low-load sealing

TF H2 is produced in thicknesses of 0.35 and 0.50 mm with a stated thickness tolerance of +/-0.05 mm. Micro hollow glass spheres are incorporated into the PTFE matrix and the material is subsequently calendered. The source attributes reduced creep tendency, improved strength and lower deformation under load to this material structure [2].

Helium leakage testing reported for TF H2 was performed at 40 bar and 80 °C, conditions selected in the source as representative of PEM electrolysis. The technical tightness class L0.01 was reached at approximately 10 MPa gasket stress. The gasket should be compressed once to at least 15 MPa to ensure this technical tightness during unloading. Above approximately 25-40 MPa, further increases in surface pressure produced comparatively small improvements in leakage [2].

From a design perspective, this behavior creates a useful sealing window at relatively low gasket stress. The objective is not to maximize gasket stress, but to ensure that the retained stress remains above the level required for the specified leakage performance while respecting the mechanical limits of the stack.

2.5.2 SH H2: highly compressed pure PTFE

SH H2 addresses the same thin-gasket requirement through a different material architecture. It is described as a highly compressed pure PTFE without filler and is likewise produced in 0.35 and 0.50 mm thicknesses with a stated tolerance of +/- 0.05 mm [2]. The high density is intended to provide reliable sealing at low bolt loads while reducing the deformation associated with conventional PTFE constructions.

In the reported helium leakage evaluation at 40 bar and 80 °C, SH H2 showed a steep reduction in leakage in the low-stress region. The source reports L0.01 at approximately 8 MPa during loading and technical tightness at approximately 5 MPa during unloading after pre-compression. Above about 35 MPa, no meaningful additional improvement was observed [2].

The distinction between TF H2 and SH H2 is relevant for material selection. TF H2 uses a filler to modify the PTFE structure, while SH H2 is pure PTFE.

2.6 Discussion: designing the sealing system rather than selecting a gasket

The experimental evidence leads to a broader engineering conclusion: electrolyzer sealing performance is governed by the interaction of material, geometry, load and time. Optimizing only one parameter can move the problem elsewhere. A highly compressible gasket may seal at low initial stress but require greater assembly movement. A low-creep material may require more stress to establish tightness. A filled PTFE may improve mechanical performance while introducing a chemical-compatibility question in a particular electrolyte.

A practical selection sequence should therefore begin with the stack boundary conditions rather than with a material name. The designer should define the process media, pressure, temperature, available gasket stress, surface condition, required tightness, allowable thickness change, dimensional tolerance and maintenance philosophy. Only then can a gasket construction be matched to the application.

The stacked-gasket work further suggests that retained load should be verified at assembly level. The dedicated test rig and the actual electrolyzer mock-up generated equivalent trends in the reported comparison, while the number of gaskets influenced creep more strongly than sealability when gasket stress was maintained [1].

This supports a two-level qualification philosophy: standardized material characterization followed by representative stack testing for the final design.

Purpose-designed thin materials provide another way to enlarge the design window. If the required leakage level can be reached at approximately 8-10 MPa instead of markedly higher stresses, the stack designer gains flexibility in plate thickness, clamping load and component deformation. This does not remove the need for sufficient installation stress or load retention; it changes the relationship between the stress required for tightness and the stress available from the mechanical system.

The same reasoning supports conservative interpretation of material data. A broad PTFE temperature range or pressure rating is a material capability statement, not evidence that the gasket has been qualified for every electrolyzer chemistry or stack design. Likewise, a successful helium leakage test is evidence of sealability under the stated test conditions, not a complete lifetime qualification. Separating material capability, test evidence and application approval is essential when translating laboratory results into design decisions.

2.7 Engineering framework

Based on the presented results, an electrolyzer sealing assessment can be organized around five questions:

- What stress is available? Determine the realistic gasket surface pressure from the stack clamping system, including structural limits of plates and frames.
- What stress is required for tightness? Use leakage data at relevant pressure, temperature, surface condition and test medium to establish a minimum sealing threshold.
- What stress remains with time? Evaluate creep/relaxation in a representative stack and account for thermal effects, retorque strategy and spring elements where applicable.
- Will the gasket geometry remain functional? Assess compression, thickness tolerance and radial material flow so that flow passages and electrochemical components are not compromised.
- Is the complete formulation compatible? Verify polymer and filler behavior against the actual electrolyte and service conditions; do not infer filled-PTFE compatibility from virgin PTFE alone.

The most robust design is obtained when the minimum retained gasket stress remains above the stress required for the specified leakage performance throughout the intended operating cycle, while gasket deformation remains within the geometric limits of the stack. This links leakage testing, creep behavior and mechanical design in one engineering criterion.

Additional leakage curves, creep-relaxation data and further experimentally determined gasket parameters presented or referenced in this work are available from the author upon request. Requests may be directed to the contact address provided in Section 7.

3 Summary and Conclusion

Electrolyzer gaskets are functional components of the stack rather than passive barriers. Their leakage behavior, creep, dimensional change and chemical compatibility can influence integrity, assembly and long-term reliability. The experimental data reviewed in this paper show that single-gasket characterization remains valuable but does not fully reproduce the mechanical response of a stack containing many compliant sealing interfaces. In the 100-gasket experiment, stress retention differed significantly between restructured PTFE and expanded PTFE, and both materials relaxed more in the stack than in the corresponding single-gasket characterization [1].

Maintaining gasket stress is therefore as important as achieving initial tightness. Start-up retorque and/or live-loading elements can be necessary depending on material and stack design. Material architecture also strongly influences the sealing window: earlier comparative testing showed required gasket stresses from approximately 12 to 30 MPa for the same stated leakage criterion, while the newer thin TF H2 and SH H2 concepts reached technical tightness at comparatively low surface pressures under the reported helium test conditions [1], [2].

Chemical compatibility must be evaluated for the complete formulation, particularly where fillers are used. The appropriate sealing solution is consequently application-specific. Reliable electrolyzer sealing requires coordinated selection of gasket material, gasket geometry, surface condition, installation stress and load-retention system. Treating these elements as one mechanical sealing system provides a more useful basis for next-generation electrolyzer design than selecting a gasket from material properties alone.

4 Acknowledgements

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5 Nomenclature

Symbol / abbreviation	***Description***
AEL	Alkaline electrolyzer
AEM	Anion exchange membrane electrolyzer
ePTFE	Expanded polytetrafluoroethylene
ePTFE-RGD2	Densified expanded PTFE
KOH	Potassium hydroxide
PEM	Proton exchange membrane electrolyzer
PQR	Creep-relaxation factor according to EN 13555
PTFE	Polytetrafluoroethylene

Symbol / abbreviation	*Description*
rPTFE	Structured / rerestructured PTFE
rPTFE-B1	Restructured PTFE with silicate (silica) filler
rPTFE-B2	Restructured PTFE with micro hollow glass sphere filler
rPTFE-F	Restructured PTFE with barite filler
Qsmin(L)	Minimum gasket surface pressure required to achieve tightness class L according to EN 13555

6 References

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