



Gas Permeation Through Fluoropolymer Tubing: What Engineers Need to Consider

Fluoropolymer tubing is widely specified where chemical resistance, temperature performance, cleanliness, electrical insulation or low friction are important.

PTFE, FEP and PFA are therefore used across chemical processing, laboratory equipment, instrumentation, medical devices and other demanding fluid and gas-handling applications.

When the medium being carried is a gas, another property may need to be considered: gas permeation. Even where tubing is completely intact and connections are leak-tight, very small quantities of gas molecules can move through the polymer wall itself. This is a normal molecular transport process within polymers and is different from leakage through a hole or connection.¹

For many applications, the amount involved may have little practical significance. Where gases are being measured at very low concentrations, retained for long periods or used at elevated temperatures or pressures, however, permeation may become more important.

Understanding what influences it can help engineers make more informed decisions about tubing material, wall thickness and overall system design.

What is gas permeation?

Gas transport through a dense polymer is generally explained using the solution-diffusion model.

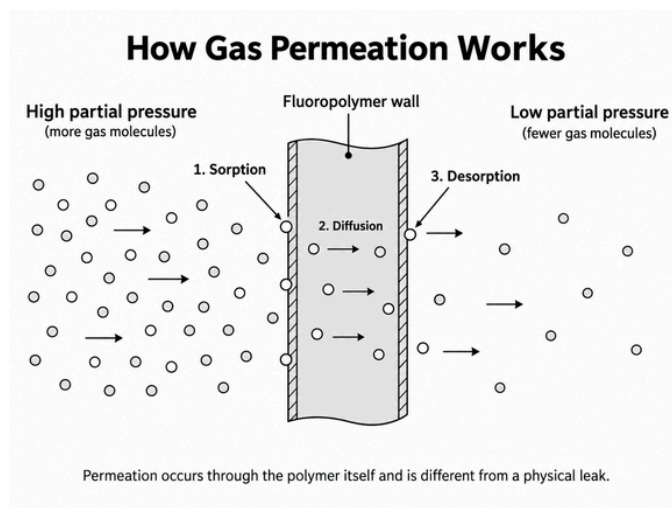
Gas molecules first enter the polymer at the higher partial-pressure side. They then diffuse through its structure before leaving at the lower partial-pressure side.¹

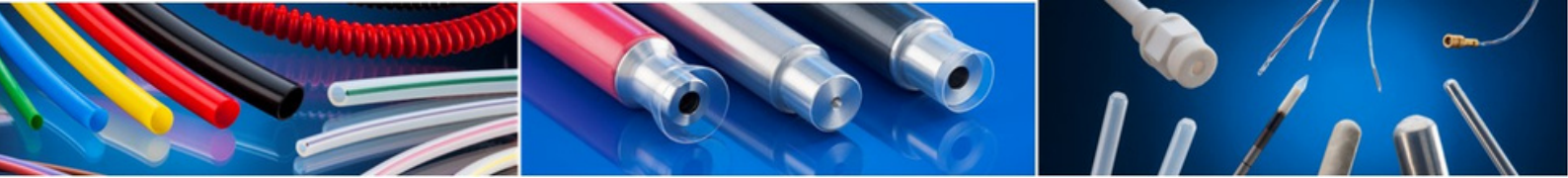
Permeability therefore depends on two main characteristics:

Permeability = diffusivity × solubility

Diffusivity describes how readily molecules move through the polymer, while solubility describes how readily the gas is taken up by it.¹

This also explains why there is no single permeability value that applies to every gas and every fluoropolymer.





What affects gas permeation?

Several factors can influence how readily a gas moves through fluoropolymer tubing.

Temperature

Temperature can have a significant effect on permeation. As temperature rises, molecular movement generally increases, allowing gases to diffuse through a polymer more readily.¹

Research into PTFE has demonstrated this effect across hydrogen, argon, nitrogen and carbon dioxide at temperatures ranging from room temperature to 180°C.²

Permeability data measured at room temperature should therefore not automatically be assumed to represent performance at substantially higher operating temperatures.

Partial pressure

Gas permeation is driven by the difference in chemical potential across the tubing wall, commonly represented for gases by the partial-pressure difference.

As this driving force increases, gas flux through the material can also increase.¹

This is separate from the mechanical pressure rating of the tube. A tube may be capable of safely containing a particular working pressure while permeation remains a separate consideration.

Wall thickness

Wall thickness affects the distance gas molecules must travel through the polymer.

Under the standard solution-diffusion relationship, increasing the thickness of the barrier reduces gas flux.¹

It is useful to distinguish this from permeability itself. Permeability describes the gas/polymer combination, while the amount passing through an actual component also depends on dimensions and operating conditions.

Polymer structure and processing

Fluoropolymers are semi-crystalline materials containing more ordered crystalline regions and less ordered amorphous regions. Gas transport occurs predominantly through the amorphous regions, meaning crystallinity can influence permeation.

Studies involving PFA have shown that changes in crystallinity associated with material grade, cooling rate and processing can affect gas permeation resistance.^{3 4}

This is one reason published permeability data should be considered alongside the grade and test conditions used to obtain it.

The gas itself

Different gases behave differently within the same polymer.

Molecular size affects diffusion, while interactions between the gas and polymer influence solubility.¹ Research into PTFE, for example, found considerably greater diffusivity for hydrogen than several larger gas molecules.²

The relevant consideration is therefore the specific gas and polymer combination, rather than a single permeability figure for PTFE, FEP or PFA.



PTFE, FEP or PFA: which should you choose?

PTFE		FEP		PFA	
					
 Maximum working temperature	260°C	 Maximum working temperature	200°C	 Maximum working temperature	260°C
 Chemical resistance	Excellent	 Chemical resistance	Excellent	 Chemical resistance	Excellent
 Low friction	Yes	 Melt-processable	Yes	 Melt-processable	Yes
 Processing	Specialist processing (required due to non-melt behaviour)	 Processing	Can be welded and re-formed	 Processing	Can be welded and re-formed
				 High-purity grades available	Yes

↓

Which material is right depends on the application


Gas type
 (e.g. air, oxygen, nitrogen, helium, carbon dioxide)


Temperature
 (operating and ambient)


Permeation
 (how critical is gas retention?)


Purity
 (standard or high-purity requirements)


Fabrication
 (welding, forming and other processing requirements)


Tubing dimensions
 (ID, wall thickness and length)

Permeation is one part of material selection. The complete operating environment should determine the final specification.

There is no single fluoropolymer that provides the best answer for every gas application.

Adtech's own fluoropolymer gas permeability reference data demonstrates that performance varies according to both the material and the gas involved, including air, oxygen, nitrogen, helium and carbon dioxide.

Permeation is also only one part of material selection.

PTFE offers excellent chemical resistance, low friction and operating temperatures up to 260°C.

FEP is melt-processable, allowing it to be welded and re-formed, with Adtech specifying a maximum working temperature of 200°C.

PFA is also melt-processable, offers operating temperatures up to 260°C and is available in high-purity grades for specialist applications.

The appropriate material therefore depends on permeability alongside chemical compatibility, temperature, purity, flexibility, fabrication requirements and tubing dimensions.



When does permeation become particularly important?

In many systems, very small levels of permeation will have little practical effect.

It warrants closer consideration where small changes in gas concentration or composition could influence performance, particularly in applications such as trace gas analysis, high-purity systems, long tubing runs, elevated-temperature environments and systems with extended gas residence times.

Research into PFA tubing, for example, has demonstrated atmospheric oxygen permeating through a tubing wall into a nitrogen stream flowing inside it.⁵

This highlights the important engineering question: not simply whether permeation occurs, but whether the amount occurring under the actual service conditions matters to the application.

Specifying fluoropolymer tubing for gas service

Where permeation could influence performance, the complete operating environment should be considered.

Relevant information includes the gas or gas mixture, concentration, pressure, operating temperature, tubing length, internal diameter, wall thickness, flow rate, residence time and acceptable change in gas concentration.

Other requirements such as chemical resistance, purity, flexibility and fabrication should then be considered alongside permeation.

Published data provides useful guidance, but comparisons are most meaningful when the test conditions are understood. Where gas retention, trace analysis or very low permeation is critical, application-specific assessment may be required before the tubing specification is finalised.

References

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