PART ONE

At Last, a Global Standard: **ISO 12101 and the Revolution in Stem Seal Testing**

Fugitive emissions from valves, pumps, and flanges account for over 1 million metric tons of losses annually. Tackling these invisible leaks could save the industry billions while preserving valuable resources. A major lever in reducing fugitive emissions lies in the sealing system, specifically stem seals.

By Colin Zegers, ITIS BV

Fugitive emissions are unintended releases of gases or vapours from equipment due to leaks, evaporation, flaring, or unplanned losses. Though often undetected during routine operations, they can accumulate to significant environmental and financial consequences.

Volatile Organic Compounds (VOCs) — a major category of fugitive emissions — are particularly harmful. Many are toxic, carcinogenic, or ozone-depleting, and contribute to smog and climate change. In densely populated or industrial areas, their odour alone can trigger complaints from nearby communities.

Regulating VOCs is not just an environmental necessity, but an economic one. Each kilogram of lost product represents inefficiency and cost. Still, the true price is often underestimated, hidden behind maintenance downtime, product loss, or regulatory fines.

While the scale of fugitive emissions varies by chemical, plant design, and operational practices, one truth holds: prevention starts with design, detection, and documentation. This is where ISO 12101 steps in.

When a Seal Fails, Everything Fails

Stem seals are often overlooked until they fail. Then, the consequences can be catastrophic. Two of the worst technological disasters in modern history — the Challenger shuttle explosion and the Deepwater Horizon oil spill — had one crucial commonality: both began with seal failure. Not due to faulty materials, but due to human misjudgement in application and assessment.

Leaking stem seal during a fugitive emissions test.

Despite their unassuming appearance, seals are precision components designed to perform under intense pressure, temperature, and chemical stress. In critical systems, their performance envelope must not only be understood, it must be respected.

In Challenger's case, an O-ring failed because of low temperatures outside its design range. The seal wasn't defective — the decision to launch in freezing conditions was. On Deepwater Horizon, a cement plug was signed off on prematurely. When it failed, full pressure surged up the drill pipe. A rubber annular preventer — the final line of defence — couldn't stop the leak, likely due to erosion and damage from earlier use.

The lesson? Seals are frontline safety components. When underestimated, the cost is measured in lives, environmental disasters, and billions in damages.

Seals often operate at the edge of a system's limits — extreme temperatures, pressures, and velocities. That makes rigorous testing, specification, and quality control not optional, but essential.

From Field to Standard: the Road to ISO 12101

Over the past 20 years, I've tested hundreds of valves, including stem seals under fugitive emission conditions. In earlier days, end users relied on their own test procedures, long before standards such as Germany's TA-Luft, ISO 15848-1, or the API 624 and 641 tests became prevalent.

While useful, these standards each serve different segments. API 624 targets rising stem valves. API 641 addresses quarter-turn valves. ISO 15848-1 is broader, covering a variety of valve types and test temperatures, but it's also more complex. TA-Luft is a regulatory emission standard with stricter leak limits, especially in Germany.

Each standard defines its own test media (methane or helium), temperature ranges, cycle counts, and leak classes. ISO 15848-1, for instance, spans temperatures from -196°C to +400°C, while API standards cap at 260°C. It also categorises stem seals by tightness (A, B, C) and endurance.

During testing, many valve manufacturers struggle to meet the requirements for fugitive emissions, like class AH — tightness class H with helium. This level is typically achievable only with bellows seals or equivalent shaft sealing. Still, end users often demand it — sometimes even for graphite seals or for valve types (such as gate or globe valves) that are not optimally designed for such performance.

And that's the crux: achieving these results depends not just on the seal, but on the entire assembly, including how it's installed. Details like the torque on the gland follower or packing compression or stress must be just right.

Too often, users rely on brochures filled with lofty promises — temperature ranges from -200°C to 800°C, for example. But in our lab, seals like these fail at 'just' 200°C. Why? Upon investigation, the manufacturer reveals: "Oh, those values are valid if you use an extension."

A valve extension places the stem seal outside the hot or cold zone — often outside the insulation — so it sits at ambient conditions. But if that's not stated clearly, is it fair to include it in the data sheet? As I often joke with manufacturers: "Can I claim car tires that last 200,000 km without wear?" They say no. I reply: "Sure — if they're only used on the spare wheel in your trunk!"

Testing the stem seal of a cryogenic valve using a helium detector with sniffer probe.

ABOUT FUGITIVE EMISSIONS

The term "fugitive emissions" covers all losses of (usually volatile) materials from a process plant, through evaporation, flaring, spills and unanticipated or spurious leaks To put the scale of the challenge into perspective, fugitive emissions in the USA have been estimated to be in excess of 300,000 tonnes per year, accounting for about one third of the total organic emissions from chemical plants, and these will inevitably be mirrored in Europe.

A typical oil refinery will have a minimum of 20,000 flanged joints connected with pumps, compressors, mixers, valves, level gauges, instruments, heat exchangers and vessels, all of which are a potential leak source. Although losses per piece of equipment are usually very small the total loss via fugitive routes may be very significant. For example, fugitive emissions from European refineries range from 600 to 10,000 tonnes of VOC's per year. In some plants in the Netherlands, 72% of VOC emissions were attributed to leakage losses from equipment, 18% from flaring, 5% from combustion, 1% from storage and 4% from other process emissions. In these plants, leakage is the greatest challenge and therefore it is crucial that programmes are established to identify leak sources and to instigate actions to minimise them.

Testing a stem seal with 'live loading', using methane as the test medium and an FID leak detector.

TECHNICAL ARTICLE

Limitations of Current Standards

API 622 offers a performance test for valve packing, simulating 1,510 cycles and up to 41.4 barg (600 psig) methane as test gas, cycling between ambient and 260°C. It uses a standardised fixture, which helps compare products under identical conditions.

But that's exactly the limitation: standardised fixtures don't reflect how seals actually perform in real valves, especially when manufacturers rely on specific geometries, coatings, or loading mechanisms to optimise performance.

ISO 12101 takes a different approach. Instead of dictating a single rigid test fixture, it provides seal manufacturers with the flexibility to define their own test setup — allowing for innovation and better real-world relevance. The fixture design must still be reported, ensuring transparency for valve manufacturers who want to replicate the performance.

Why ISO 12101 Was Needed

For years, I believed a new standard was essential — one focused specifically on stem seals. Too often, critical data like minimum surface pressure, installation instructions, or true performance limits were missing from documentation.

Rather than pursue a national or European (CEN) standard, I contacted NEN (Royal Netherlands Standardisation Institute) in 2019 to propose an international ISO standard directly. Since then, I've served as Team Leader of ISO/TC 153 WG 5, the group behind ISO 12101.

From the start, we aimed to include the entire supply chain. I invited both ESA (European Sealing Association) and FSA (Fluid Sealing Association) — key stakeholders representing the global sealing industry — to actively participate. ESA alone includes over 50 companies, with 12,500 employees and billions in annual turnover. Although one might expect resistance from seal manufacturers — after all, testing costs money — the opposite has proven true. ESA and FSA now support the standard. They understand its long-term value: a shared benchmark that raises quality, improves performance, and builds trust across the industry.

ISO 12101 for Valve Stem Seal Qualification

ISO 12101:2025 is officially titled: "Industrial valves — Measurement, test and qualification procedures for fugitive emissions — Classification system and qualification procedures for type testing of stem seals for valves." It establishes a method for classifying and qualifying valve stem seals, enabling manufacturers to select proven sealing systems that meet the requirements of ISO 15848-1.

The standard, which applies to linear and quarter-turn valves, covers the following:

- Compressible packing (with or without live loading)
- Pressure- and spring-energised seals
- Elastomeric systems

By testing stem seals under pressure, with temperature cycling and tracer gases (such as methane or helium), ISO 12101 assigns leak-tightness and endurance classifications, providing engineers with the data they need to make informed, emission-conscious design decisions.

It's not a replacement for full valve testing — that's still the realm of ISO 15848-1 — but it is a critical new tool in the fight against fugitive emissions.

Conclusion

ISO 12101 was released in June 2025 and marks a major leap forward in sealing technology. Its goal is simple but ambitious: to reduce unnecessary emissions from stem seals in industrial valves. By offering clear guidelines and performance benchmarks, the standard empowers valve manufacturers, end users, valve overhaul companies, and regulators alike. It brings transparency, comparability, and —above all — trust.

SOURCES OF FUGITIVE EMISSIONS

A significant proportion of fugitive emissions are losses from unsealed sources, including storage tanks, open-ended (non-blanked) lines, pressure-relief valves, vents, flares, blowdown systems, spills, and evaporation from water treatment facilities.

These are part of the industrial process, anticipated (usually) by the process operator, and will not be considered further here. In other cases, these losses may be caused by leaks in the sealing elements of particular items of equipment, such as valves 50%-70%, pumps 10%, flanges 5%, compressors 3% and agitators/ mixers 2%.

Source : www.esaknowledgebase.com

Stem seal failure after a few operational cycles at room temperature.

Stem seal leakage after high-temperature testing.

COMING NEXT IN PART 2:
How the standard works in detail — how to test, how to certify, and what information is essential for seal suppliers, valve makers, and service providers.

ABOUT THE **AUTHOR**

Colin Zegers is the founder and managing director of ITIS BV, an ISO 17025-accredited test laboratory and Conformity Assessment Body (CAB) based in the Netherlands.

With 27 years of experience in leak testing, valve and product testing, and industrial inspections, he has built a reputation for combining technical depth with practical implementation.