Tip of the month/No. 20

Watertightness

Question: In a design drawing, I found a tightness specification. The leakage rate was specified as "watertight". What does this really mean in the context of leak detection?

Answer: There isn't a clear-cut answer really. First, we should establish what we mean by "watertight". Then the question must be clarified whether we allow the accumulation of a drop or liquid film on the surface of the component being tested, or if any escape of water is permissible at all. These counter-questions show us clearly that the colloquial term "watertight" isn't suitable for defining a tightness specification.

Background: For example, watertightness can be expressed phenomenologically, or in other words, descriptively. ISO/TR 11340:1994-07, Rubber and rubber products - Hydraulic hose assemblies - External leakage classification for hydraulic systems describes the leakage of fluids and classifies it in five different classes (see figure 1). This allows a worker to make an evaluation; however, it does not provide us with quantification.

Class 1:
No moisture escaping

Class 2:
Fluid escaping without droplet accumulation

Class 3:
Fluid escaping with non-falling droplet accumulation

Class 4:
Fluid escaping falling drops

Class 5:
Fluid escaping, whereby the frequency of falling drops amount to a measurable liquid stream

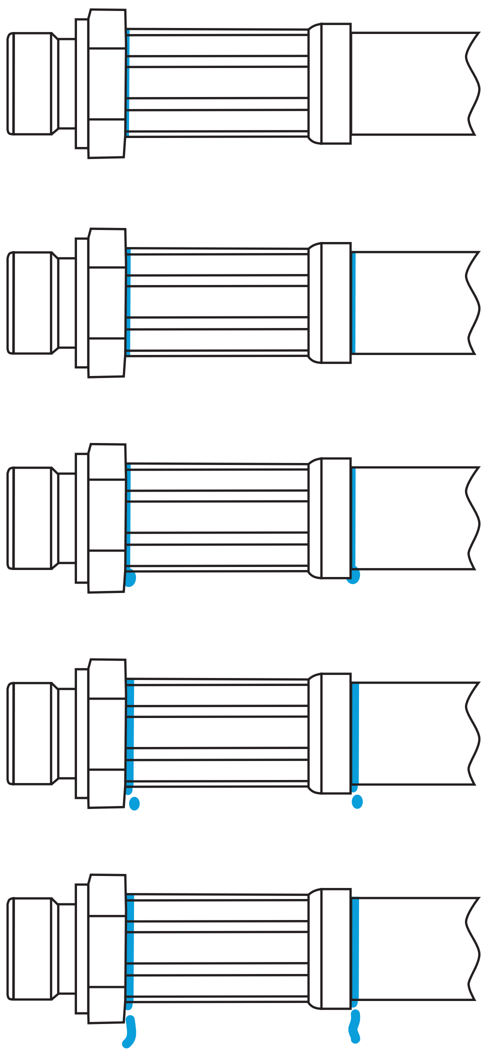

Figure 1: Leakage classification according to ISO/TR 11340: 1994 (E)

Let us try to derive quantification for a tightness test by observing leaking water. To do so, we shall recruit the formulas compiled in our "Leak Detection Compendium" to convert a fluid leak rate into a tracer gas leak rate. Let's assume that while we are skiing down a slope in winter some colored drop in the white snow would annoy us. Thus, a snow groomer must not lose any drops from its cooling water line. This allows us to classify the cooling water line as class 3 of ISO/TR 11340.

Let's assume that the leaking water bubble is spherical, with a diameter of 2 mm. This means the bubble has a volume of approximately 4.2 mm^3. Once this bubble emerges, it will either freeze in low temperatures, or it will vaporize within 10 minutes in temperatures above 0°C. This gives us a maximum fluid leak rate of 4.2 mm^3 in 10 minutes, or approximately $7 \cdot 10^{-3}$ mm^3 per second. The conversion to a helium leak rate is done with the formula:

$$Q_{He} = \frac{\eta_{flüssig}}{\eta_{gas}} \cdot Q_{Wasser} \cdot \frac{p_1 + p_2}{2}$$

η_{liquid}	= Dynamic viscosity of the liquid		[Pa·s]
η_{gas}	= Dynamic viscosity of the tracer gas		[Pa·s]
p_1	= Supply line pressure (abs)		[bar]
p_2	= External pressure (abs)		[bar]

using these values

η_{liquid}	$= 1.0 \cdot 10^{-3}$	[Pa·s]
η_{gas}	$= 1.86 \cdot 10^{-5}$	[Pa·s]
p_1	= 3	[bar]
p_2	= 1	[bar]

which gives us a helium leak rate of approx. 0.75 mbar·l·s^{-1}. If this rate is then calculated for a test pressure of 1 bar against vacuum, we obtain approx. 0.1 mbar·l·s^{-1}. Now, if we were to assume the case of steam-sterilization of optical medical devices, then the water drop should of course be substantially smaller than the resolution that the treating physician's eye can register. By assuming a droplet diameter of ¼ mm, we'll arrive at helium leak rates in the vicinity of a couple of 10^{-6} mbar·l·s^{-1}.

In the above examples, we have water in liquid and steam form - does "watertight" really cover such a broad area, particular with respect to the liquid aggregate state.

A literature search procures the following representative statements on watertightness (www.dgzfp.de/Fachausschüsse/Dichtheitsprüfung/faq; FAQ 22, in German):

Leak rate / $mbar \cdot l \cdot s^{-1}$	Leak rate / $Pa \cdot m^3 \cdot s^{-1}$	Diameter of the leak channel / m	Leakage at 1 bar differential pressure
10^2	10^1	$1.0 \cdot 10^{-3}$	Water escapes
$10^0 = 1$	10^{-1}	$1.0 \cdot 10^{-4}$	Water spigot starts dripping
10^{-2}	10^{-3}	$3.5 \cdot 10^{-5}$	Approximately the diameter of a hair; minimum requirement of “won't drip“
10^{-3}	10^{-4}	$2.0 \cdot 10^{-5}$	“waterproof“

These are mostly calculated values, also resulting in differences in published tables for leak channels, a leak in a relatively thick wall, and aperture leaks, a leak in a very thin wall. The values of the above-mentioned table certainly provide clues for a sensible range of the specification; however, they do not suffice for an actual quantification.

The maximum diameter of an opening through which a liquid can no longer escape is calculated with the following equation.

$$d_{max} = \frac{4 \cdot \sigma \cdot \cos\phi}{\Delta p}$$

σ	= Surface tension	$[N \cdot m^{-1}]$
ϕ	= Wetting angle	
Δp	= Pressure difference between beginning and end of the leak channel	[bar]

Here, dynamic viscosity is no longer the defining parameter, but is replaced by surface tension.
As the wetting angle is usually unknown, it is assumed to be 1 - this is the largest value a cosine can take, and thus also the worst case scenario for a leak rate. The surface tension of water at 20°C is stated as $72.8 \cdot 10^{-3}$ $N \cdot m^{-1}$ in reference tables. However, this only applies at this temperatur for non-low surface tension water on aluminum

If one changes the temperature, adds a drop of a surfactant (dishwashing detergent) to the water or uses a water-repellent plastic as a surface, the water will crawl through channels the surface tension would otherwise easily block - thus, “watertight“ can easily change from 10^{-2} $mbar \cdot l \cdot s^{-1}$ to 10^{-5} $mbar \cdot l \cdot s^{-1}$ in no time.

It gets even worse if minute quantities of water evaporate from the surface of a calotte of a small water-filled leak channel, increasing the weight of oscillating crystals or corroding contacts or electrical lines inside the enclosed housing of an electronic component – it doesn't take long here to get into the 10^{-8} $mbar \cdot l \cdot s^{-1}$ range.

These examples are intended to illustrate that “watertight“ really covers a broad and dynamic range of leak rates, and that a catchword can never be used as a quantitative tightness specification.

You are welcome to reproduce the estimations of this tip with the formulas found in our leak detection compendium (now available in German!). More information on leak detection and tracer gases can be found on our website http://leak-detection.pfeiffer-vacuum.com.

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