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WHAT IS A LEAK-PROOF PRODUCT?

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Leak/Flow Detection

We test, You produce.

INTRODUCTION

In everyday practice and in many areas of life, we deal with objects, products, devices whose important feature is tightness, ensuring their proper use in various conditions. Such products found in our daily practice are, for example, parts used in cars (tires, tanks, EV batteries, brake, cooling and air conditioning systems, etc.), household appliances (refrigerators, gas stoves, washing machines, dishwashers, coffee machines, etc.), packaging, medical devices (syringes, vials, blisters, ...), water and gas fittings (valves, water filters, dispensers,...), electronic devices (watches, phones, module-sealed housings batteries...), and many more.

Manufacturers of these devices **should ensure the quality of their products, min. through appropriate quality control in the production line.** One of the parameters indicating the proper quality of the product is its tightness, so it is also necessary **to control this feature of the product at the production stage.**

In the colloquial understanding, the feature of the product which is tightness is defined in a "zero-one" way, i.e. the product can be tight or leaky. Such a feature defines the product only in a qualitative way, because we could similarly say that the product is "heavy" or "light", or "long" or "short". It can be seen that the product feature formulated in this way is imprecise, because criteria and tolerances are needed to quantify this parameter, which is tightness.

➔ A good example of colloquially understood leak control is testing a leak from a car tire, when the wheel is immersed in water, and observing air bubbles escaping from the tire in the case of a leak. Then we can conclude that if an air bubble appears, the tire is leaking. We then make a "qualitative" distinction: the product is leak-proof or not leak-proof. At this point, the question can be asked:

- What will happen if the bubble appears only after a minute of observation?
  Either 10 minutes or after an hour... etc..

- How long should we observe the tire underwater to make a proper "tight/leaky" assessment?
  It can be seen that this type of leak control is not very precise, because we have not provided a "quantitative" criterion for the assessment of this feature of the product.

WHY LEAK TESTING IS SO IMPORTANT?

In the production process, if the quality control process should be more or less automated, **we must measure a certain value defining the tested feature of the product, and then compare the result of this measurement with the adopted criterion determining the correctness of the parameter describing this feature.** Such criteria are referred to as technical specifications for the product, which should be specified at the stage of developing the product structure in such a way that the product is adapted to its intended use and ensures its proper use by the future user. **Such criteria may concern, for example, dimensions with a given tolerance, weight, electrical, thermal parameters, etc., always with tolerances acceptable for a given parameter.**

1. HOW TO DETERMINATE A LEAK RATE?

The above remarks apply equally to the need to determine the tightness of the product in a quantitative manner, and to provide a criterion allowing for the qualification of the product as good (OK, tight) or bad (NOK, leaky).

Therefore, **we need to define a certain parameter that will indicate the "degree of tightness"** of a given product, and provide a range of values of this parameter, at which we will be able to qualify the product as "good" (OK) or "bad" (NOK).

Such a parameter, which we will define, will be a value that **we will call "leak rate",** hence we will mark with the letter L. We can now formulate a criterion for this feature of the product, which we will call:

- **"Value of Acceptable leak rate" (L_{max}).**

It is very common to find a statements that since the product should be tight, no leakage can be allowed. However, in nature there is no concept of absolute tightness, just as it is impossible to create an absolute vacuum, or a temperature of zero Kelvin... In the example with the tyre, our evaluation criterion also depended on the time in which we observe the tested tyre. If we do not notice a leak for e.g. a minute, it does not mean that a bubble will not appear after a longer time...

The tightness of the product, like any other feature, **should be adapted to its intended use and ensure its proper operation in the assumed conditions.** There will be a different criterion, for example, for a valve operating in a nuclear power plant, and another for the exhaust system in a car, different for a high-pressure tank for hydrogen, and different for a bathroom faucet....

Leakage can occur as a result of a defect in the wall of the product, it can be e.g. crack, porosity, lack of adhesion, sealing defect, material defect, etc. Leakage is defined as the amount of a substance (gas, liquid...) escaping per unit of time from the tested product, as a result of the existence of this defect.

For a liquid (e.g. water), the definition of a leak would be:

$L=dV/dt$, where dV is the volume of the liquid and dt is the time.
Since liquids are incompressible, **the dV value is a good indication of the amount of substance escaping from the product.**

For a gas, in order to determine the amount of gas coming out, we should **give the pressure at which this volume is measured.** This results from the equation of the state of an ideal gas (Clapeyron equation) which relates the parameters describing the state of the gas: **pressure (P), volume (V) and temperature: (T).**

$PV=nRT$ (n is the number of moles of gas, R is the gas constant)

Thus, the product of P*V is a measure of the amount of gas at a given temperature.
The definition of a leak for a gas (e.g. air) is:

$L_g = PdV/dt$

The above definition determines in the units in which we define a leak (in the SI system):
[PdV/dt] = Pa * m^3/s, which is Pascal times a cubic meter per second.

- **As a reminder:** Pascal (Pa) is a pressure equivalent to a pressure of $1N/m^2$ (one Newton per square meter). This is a very small amount, corresponding to, for example, the pressure exerted by a 0.1 mm thick layer of water. Atmospheric pressure (1 bar) is 100,000 Pa, i.e. 1 Pascal is one hundred thousandth of atmospheric pressure

In practice, other corresponding units are used to describe a leak, the most commonly used include:

- mbar * L/s (millibar liter per second, a unit often used for helium tests).
- atm*cm^3/s or atm*ml/s (atmosphere milliliter per second, a unit often used in the U.S.).
- bar*cm^3/min, (bar cubic centimeter per minute) if leakage occurs into the atmosphere.

This last unit is quite commonly used in leak tests of products in production, because then we are dealing with the measurement of the volume of air escaping into the atmosphere from the tested product. Since the volume is measured at a pressure of 1 bar, this unit is often "simplified" and the leakage value is given in an abbreviated form:

- cm^3/min or ml/min

However, it should be remembered that in any calculation it is necessary to take into account the fact that there is a "hidden" value of 1 bar in this quantity.

The leakage value given in this unit **(cm^3/min)** also has a simple, intuitive interpretation: with the immersion test in water. It is simply the total volume of air bubbles escaping from the product per minute, e.g. a leak of **5 cm^3/min** means that when the product is immersed in water, a total of **5 cm^3** of air bubbles will escape in **one minute.**

The relationships between leak values expressed in different units are as follows:

- 1 Pa*m^3/s = 10 mbar*l/s
- 1 (bar)* cm^3/min = 1,67*10^{-2} mbar*l/s= 1,67*10-3 Pa*m^3/s

A common industry leak unit is an "not-formal" unit:

- 1 sccm

which is an abbreviation of the English words: **"standard cubic centimeter per minute". This means leakage into the atmosphere under standard conditions, i.e. at a temperature of 20oC and a pressure of 1013.25 hPa.** This unit is basically the same as **1 cm^3/min** (for 1 bar), it only contains a specification about the ambient conditions.

Properly formulated requirements for the "class" of product tightness should therefore contain information about the permissible amount of medium (e.g. air) escaping from the product per unit of time, if it is filled with this medium at a specific pressure.

Thus, the specifications for product leak testing should contain two parameters:

- Test pressure, **P,** (when determining which medium we use for the test – most often air, helium...).
- Maximum permissible leakage value **(L_{max}).**

An example of such a specification is the requirement for a car radiator at one of the manufacturers (air test):

- Test pressure: 2 bar
- Acceptable leak rate value: 1 cm^3/min

One could ask why we allow such a leak for a product which is quite an important part of the engine cooling system in a car.

The radiator contains a water-based coolant during operation. The test, on the other hand, is performed using air, which penetrates through small holes much more easily than water. **The difference in viscosity** of the two fluids is important here: water has a viscosity about two orders of magnitude higher than air.

The difference in viscosity for the oil-air system is even greater, hence the acceptable air leak rate values for products containing oil (e.g. car engine lubrication system) are even greater, e.g. for the oil circuit in the engine head at one of the manufacturers:

- Test pressure 500 mbar
- Acceptable leak rate value: 10 cm^3/min

One of the most **important "challenges" for the product designer (as well as for the manufacturer) is the correct determination of the quality requirements that the product must meet** for such a features as tightness.

The question may be asked how the specifications for tightness are created, formulated by designers or manufacturers, to ensure the proper operation of the product.

There are several methods to determine such a parameter as the permissible leakage value.

1. The first is the **analysis of physical phenomena related to the flow/leakage of a specific medium by a defect causing a leak.** Such a theoretical analysis can be carried out on the basis of the laws of physics for the flow of substances through theoretical models of product defects. There is, for example, a simplified model of flow through a defect, in the form of a round hole in the wall of the product and a given diameter, at the given pressures on both sides of the hole. Assuming a laminar (viscous) flow, the **Hagen-Poiseuille law can be used** for the flow of gases and liquids through such an hole.

In addition, phenomena such as surface tension for the liquid (blocking the leakage in some cases), different defect geometry, etc. can be taken into account. Such an analysis allows, for example, to determine at what air leakage value (at a given pressure) the liquid will not escape from the product (the product will be tight to this liquid). **Such analyses are used for many products in which there is a liquid during operation and the test is performed with gas (air, helium,...).** Phenomena related to flow (leakage) due to real defects of various kinds are described by complicated laws, however, the use of simplified models allows for a relatively good determination of the Lmax value (e.g. for air, at a given test pressure). Such models **also allow for the analysis of the dependence of the leakage on the diameter of the defect** (or its geometry in general), **on the test pressure, viscosity of the medium, etc.** More detailed data on this topic can be found in the literature on the subject, training materials, and the Internet.

2. Another method to determine the specifications for the product leak test is **to perform a leak tests using a selected production method (e.g. air), and then to carry out experimental tests in simulated conditions of real operation of the product.** On the basis of the comparison of the results, it is possible to find correlations between the results of tests used in production (e.g. with the use of air) and the appearance of defects that can be encountered during the use of the product. In other words, **we can determine what air leakage can be allowed in given conditions, so that it does not affect the proper use of the product.** There are many studies available in the literature describing the results of experiments consisting in finding a correlation between air leakage and leakage for different liquids for the same defects. In particular, such research was carried out for the automotive industry, where many parts and subassemblies contain liquids such as fuel, brake fluid, coolant, oil.

These liquids work in different pressure and temperature conditions, so it is necessary to simulate such conditions in experiments, and determine what defect of the product we can still allow so that it does not affect the actual operation of such a component in the car. In the conditions of serial production for such a car part, tests are usually performed by air, hence the need to find correlations between the results of tests carried out using different methods. One example of such a method of determining the requirements for the leak test is also the testing of water fittings for common use (valves, taps, connectors, etc.).

The test consists in testing workpieces with defects detected by the air method and using water under simulated operating conditions (at different pressures and temperatures).

2. WHICH OTHERS CRITERIAS CAN DETERMINE A LEAK RATE?

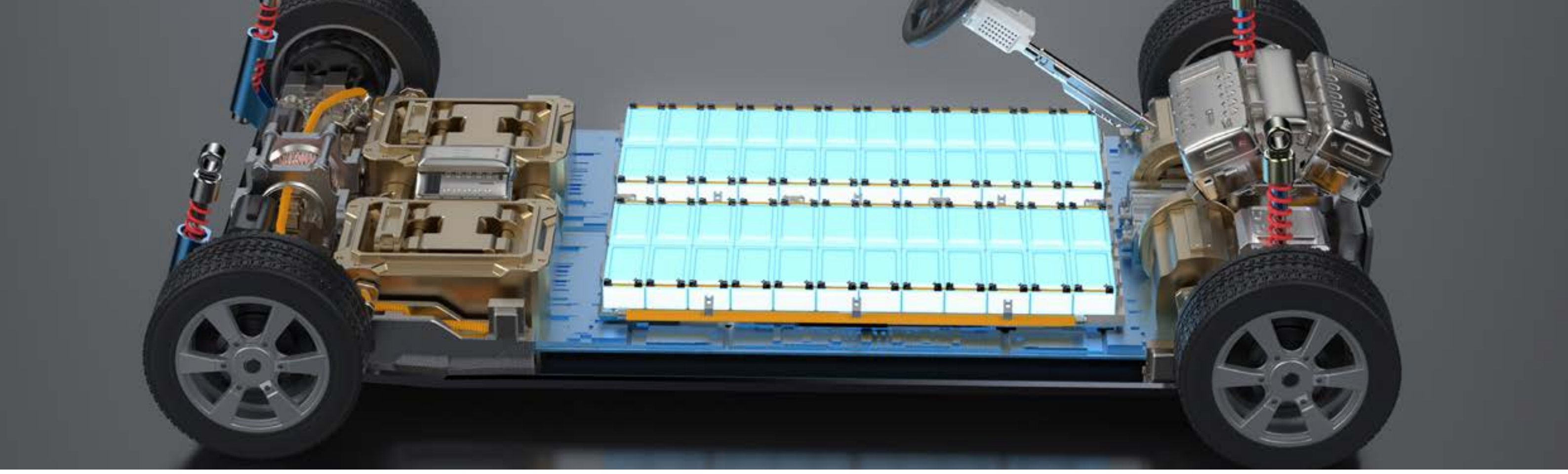
Specifications for the leak test are often **given directly in the standards for a given type of product,** these are often the standards that apply to all manufacturers of a given industry, in a given country or in the world. An example is the standards for the tightness requirements of gas fittings for domestic use, where the following conditions are explicitly stated: permissible leakage **of 1 cm³/min** for a test with air at a pressure of **150 mbar.** Similarly, in generally applicable standards, specifications for the tightness of air conditioning and refrigeration systems are given. For these products, the permissible leakage value results from the permissible loss of the refrigerant during the period of operation. A typical value found in the standards is a maximum loss of **1 gram/year.** Some manufacturers have their own standards for a given type of products, defining their quality properties on the basis of previous research and production and exploitation experience.

Therefore, if a manufacturer of a similar product would like to formulate its own specifications, it can use the experience of other manufacturers, or standards, if they are generally available.

A very important factor influencing the determination of tolerance for each parameter determining the quality of the product are economic considerations. According to the principle of **"fitness for purpose"**, i.e. adaptation to the intended use, the product should meet certain quality assumptions to such an extent that it can be properly used, and at the same time its price is acceptable to the user. In highly competitive conditions, manufacturers try to adjust quality parameters so that the production process is profitable and the product can be sold on the market. This involves some "optimization" of production processes, which can sometimes reduce quality. **As we can see, it is a certain trick to find a compromise between economic factors (price, profitability of production) and quality parameters of the product, which depend on the production technology used, quality control, etc.**

The requirement of an appropriate "class" of tightness for the product is also one of the parameters where such a compromise is needed. For example, manufacturers use different leak testing methods and different leakage limits for the same product. As an example, we can mention the elements of the fuel system in a car, where values from **less than 1 cm³/min to several cm³/min can be found.** In the case of high requirements for the tightness of the product, helium methods must be used for testing, which are much more expensive than air methods.

Hence, for example, the prices of cars in which such components with "stricter" criteria are installed, can differ even several times depending on the car brand.



In addition to the economic aspects for the formulation of specifications for the tightness of the product, it is necessary to mention very important other factors that must be taken into account, such as the safety of use of the product, its impact on the environment, etc. Only the combination of all aspects: technical, technological, economic, environmental and safety allows for the proper determination of the specification for this feature of the product, which is its tightness.

The formulation of requirements for the product leak test, in **the form of specifying the acceptable leak rate for air at a given pressure, allows to assess, in a certain sense, the geometry of the largest permissible defect of the product (diameter, shape, form of the defect),** for which the correct use of the product in accordance with its intended purpose is still ensured. This is mainly used for products in which there is a medium in the form of a liquid or gas during operation, and the leak test allows to check whether, under the assumed requirements, the medium will not escape outside the product during use. An example is parts and components in automotive production, where tightness must be ensured due to the possibility of leakage of various fluids. Such tightness is assumed to be ensured if the size of any defects in the product does not exceed certain sizes. Then, in production air tests, the permissible leakage is directly related to the maximum size of the defect.

There are also other formulations of specifications for production leak tests, depending on the type of product and its operating conditions.

If we are dealing with a product in which a constant pressure should be maintained for a certain period of time, tightness can be defined as the maximum permissible pressure drop during operation. An example is the car tire mentioned above, in which the tightness can be determined assuming that the pressure does not drop more than, for example, 0.5 Bar during the year. Of course, when testing such a tyre in the production process, we do not have such a long time to detect this assumed maximum pressure drop. The question arises as to what method and at what parameters of such a test should be performed. If a leakage value is measured, the criteria in the form of a permissible leakage value should be linked to the pressure drop requirements. Then, by performing a quick leak measurement, we detect defects in the product that could cause its leakage. However, there is a problem with such a direct relation between this leakage value (which corresponds to a certain size of **a single defect**) and the pressure drop in the product, because it may happen that there are many micro-defects in the product (undetectable by leak testing equipment), which in total cause a greater pressure drop than assumed. Therefore, in such cases, methods for measuring pressure drop will be more reliable.

Another example of a different formulation of specifications for leak testing is the requirements for refrigeration and air conditioning systems, where the maximum amount of refrigerant gas that can escape in the long term is given. The most common leakage limit for such device is **1 g/year** (one gram per year). If the tests are carried out in the production process, e.g. using the helium method, appropriate conversions of this limit value should be made into a leakage value for helium, generally given in units of **mbar*L/s** (millibar liter per second).

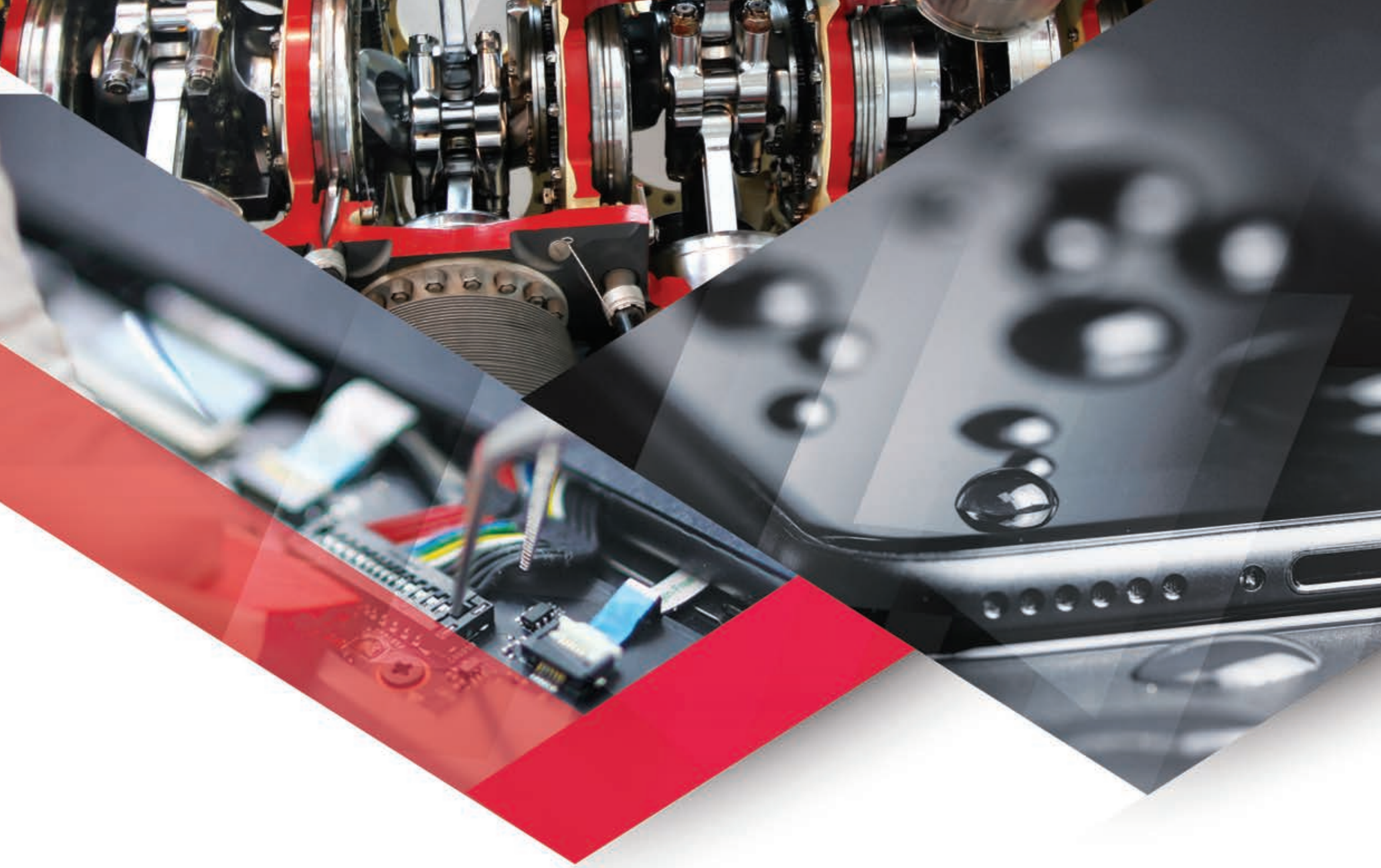
In the packaging, cosmetics and medical industries, there are sometimes the specifications for leak testing, in the form of **the maximum diameter of the defect that must be detected** (e.g. 0.05 mm). When using a production test method, either by means of pressure drop or leakage measurement, appropriate calculations should also be made using the laws describing the dependence of the leak (flow) on the geometry of the defect. It should be remembered that such theoretical relationships apply to simplified conditions (e.g. regular shape of the defect), so they can be the basis for an approximate determination of the acceptable leak rate value. In such a case, it is also possible to confirm the assumed values by performing measurements on products with standard defects, or with the participation of appropriate leakage calibrators and masters.

Another important area in which leak tests are used is the production of parts that should be airtight due to their use in changing **environmental conditions.** This applies to e.g. devices exposed to precipitation, immersion in water, dust contamination with moisture, etc. For such devices, the requirements of airtightness are defined by IPXX standards, which specify to which external factors the product should be resistant. An example is the IP67 standard, which requires the product to be sealed when immersed in water to a depth of 1 m for 30 minutes. A similar requirement is the water resistance of the watch, when submerged, e.g. to a depth of 50m. At this depth, there is a pressure of 5 bar, which immediately determines the requirements for the pressure at which the test should be performed.

Other IP standards specify the requirements for "splash-proof" and "dust-proof", etc. Again, the problem arises how to select the conditions for production tests of such products so that they meet the requirements of IP standards. In mass production, where rapid air tests are used, it is impossible to reproduce the conditions formulated in these standards. **Therefore, it is necessary to carry out appropriate calculations or perform comparative tests to find correlations between the requirements of the standards and the criteria for the leakage values measured in the production tests.**

The problem of airtightness of devices according to IP standards or similar standards and conditions for testing tightness in production is emerging more and more often in various fields. An example is the entire electric car industry, where it is necessary to ensure adequate tightness for batteries, electronic components, wiring, etc. Other examples are the production of waterproof devices containing electronic components inside a sealed case, such as mobile phones, watches, sensors, telecommunication components, cameras, etc. Such devices should be tested in the mass production process, so it is necessary to formulate specifications for leak tests in such a way that they can be adapted to the requirements of the relevant standards and to ensure their proper operation.

To sum up, in order to ensure proper leak testing of products in the mass production process, **it is necessary to formulate requirements and specifications specifying the testing method and parameter values to determine whether a product is "good" (leak-proof) or "bad" (leaky).** Depending on the type of product and its intended use, it is often necessary **to adjust the acceptance criteria** for the measurement of the leakage rate (during production tests) to the quality performance assumptions for the product. This involves the need to carry out analyses using laws describing relevant physical phenomena, or the results of laboratory research and experiments, and taking into account economic, environmental and safety aspects. Therefore, it is necessary to have extensive knowledge in various fields and extensive experience to solve many issues related to product tightness testing in production conditions.



CONCLUSION

Thanks to their competence and many years of experience in the use of various leak control methods in many areas of production, ATEQ engineers have the knowledge to propose solutions related to the testing methodology, selection and optimization of test parameters, definition of criteria and specifications for quality control in production.

The transfer of knowledge can take place through **consultations, participation in tests and experiments related to a specific applications,** as well as through training organized in the Company's office or at the Client's premises.

ATEQ's offer includes instruments and devices that can be used in practically all applications in production, from detectors operating on the principle of air pressure drop measuring, through direct testing of flows and micro-leaks using air, helium, hydrogen and electrical methods.

ATEQ engineers provide their knowledge and experience at every stage of the implementation of leak control in specific applications in the customer's production plant.

"Through education and passion physicist. He obtained a Doctor of Physics degree andwas a doctoral student at the University of Warsaw. For 10 years, he was a university lecturer at Warsaw University's Faculty of Physics, then worked for six years atthe Polish Academy of Sciences, dealing, among other things, with non-destructive research. The next career step was to work in the early 1990s for the French company ATEQ, with which it is still associated today. He was President ofATEQ Poland before handing over the subsidiary's management to his sonWojciech Wojdowski in 2022."

Włodek Wojdowski, ATEQ Poland

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