

ANALYSIS OF CURRENT METHODS FOR LEAKAGE PART DETECTION

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Abstract: There is a constantly growing need for products and technologies that for their realisation require hermetically closed elements, vessels and tubes. Envelopes with greater or smaller vacuum tightness had to assure a satisfactory isolation between external atmosphere and inside over- or under pressure. Critical leak spots in closed systems are usually: connections, gaskets, welded and brazed joints, defects in material etc. Regarding to quality demands in different production processes, technical people very relate to standards for tightness testing.

With the view of stating if an element or system meets with the corresponding standards, we have to be familiar with the procedures relating with the following aspects:

- question if there is a leakage or not
- settlement of the leak size
- detection of leak location

For solving the mentioned problems, different treatments and techniques are known, but among them there is no a universal method. Each testing is suitable for a selected leak rate only, or for fixed forms and technologies. Our article presents the leak types, their sizes and various leak detection techniques.

Keywords: Leakage Detection; Leak Flow; Differential Mass Flow Test.

1. Introduction

Leak testing is an important quality control test in the manufacturing industry. Since there is no such thing as a completely leak-free component, the key is to determine what leak rate is acceptable in order to manufacture products that are safe and adequate for the customers' needs.

The leak testing (or "leak test") is the industrial proceedings necessary to verify and to measure the pneumatic tightness of the produced components. This phase of the industrial process is also called leak test or leakage detection.

Historically, the companies that are better equipped in this production phase are those producing parts or goods that are essentially very dangerous, or with high technological value.

Leak detection has been used for a wide range of products for only a few decades.

Recently, the advantages of using this test method for less dangerous products have been discovered. If, for example, small oil leaks in motors or in mechanical transmission were considered acceptable in the seventies and in the eighties, from the nineties a little defect of this kind meant a non-conformity by the final customer. Thanks to the application of this principle of technical availability with quite short times and low cost these testing

methods expanded, and it continues to expand. We can generalize that any product that may contain some gas or some fluids can benefit from these tests.

In the early days of leak testing, it was common to dive a part under water to look for bubbles to detect a leak in the piece. Although this primitive method was simple and cost-effective, it was also time-consuming and did not provide accurate quantified leakage rate data. Often there is no detrimental consequence if components have a small leak, but the question is how many bubbles would be acceptable over a given time.

Air leak testing technology quickly became a game-changer in the manufacturing industry. Air leak testing tools could be programmed and automated in production lines to quickly and accurately detect tiny leak rates, greatly reducing test times, increasing production, lowering waste, and lowering the cost of production.

2. General Steps for Part Leak/Flow Test

The automatic air leak testing equipment creates a speed or pressure difference between the area considered airtight and the outside of the test body. Each system can perform this test with different methodologies.

These systems are running a test cycle based on a few basic steps:

- Filling - to pressurize the part that is being tested (figure 1)

In general, the filling can be done with both positive and negative pressure, [1] both with pressure (or depression) applied from the inside or outside of the part that is being tested.

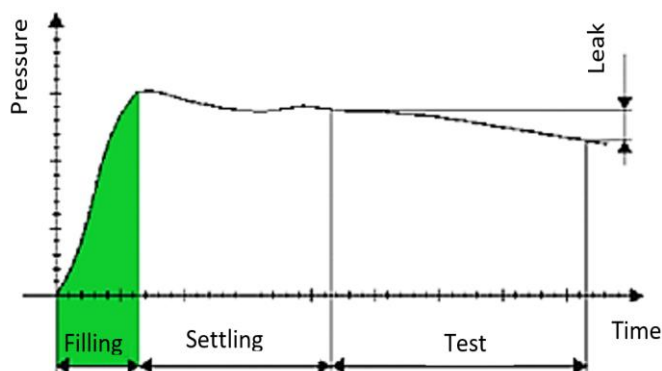


Figure 1: Filling stage

- Settling - to stabilize the volume of air blown (figure 2)

The settling phase is necessary to stabilize the pressure or the values of the leakage measurement flow.

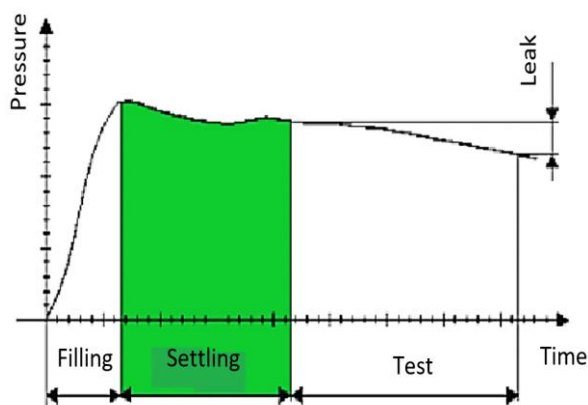


Figure 2: Settling stage

- Testing - to determine the loss of pressure over time (figure 3)

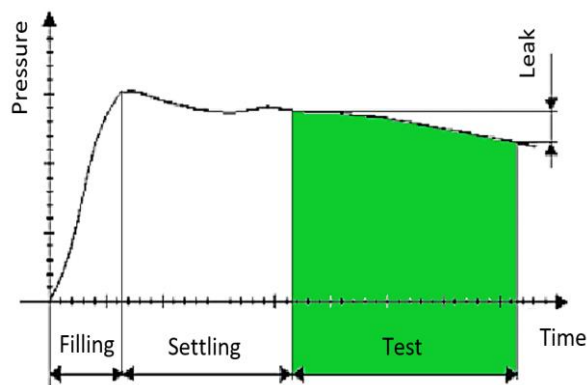


Figure 3: Testing stage

3. Systems/Methods used to Measure $\Delta p/\Delta t$:

3.1 Absolute System

The absolute system (figure 4) is the most immediate, economical, and obvious theoretical method to measure the pressure drop.

A single pressure transducer is used in an air decay test to measure the test pressure and the pressure drop from a leak. The sensor must be sized for the test pressure; therefore, the sensor's range must be greater than or equal to the test pressure. For example, 1 bar test pressure requires at least 1 bar full scale sensor (1000 mbar). The piece is filled in a given time then is stabilized. After these two steps, the test pressure is measured part that is being tested at the beginning of the test time. The leak is measured as the test pressure drops over time then is multiplied by the part's volume.

An air pressure drop test is best suited for testing leaks that have a pressure drop per second higher than the sensor accuracy.

For example, a 1000 mbar sensor with 0.05% accuracy, could be used to test a 30 sccm (standard cubic centimetres per minute) max. leak from a 1-liter part or 0.5 mbar/second (50 Pa/s). Measuring the leak or pressure drop for 10 seconds would cause a 5-mbar (500 Pa) pressure drop that is 10 times the sensor's accuracy. A 2000 mbar (200 kPa) test pressure would double the test time or the max. sccm leak rate or would require the test volume to be reduced by half.

The elements that come to limit the precision are the electrical noise of the circuit and that mechanical one of the transducers, that correspond to the resolution or maximal number of points within which the full-scale measure is decomposed. Much higher it is this resolution parameter and shorter it will be the time that is necessary for the decay measure.

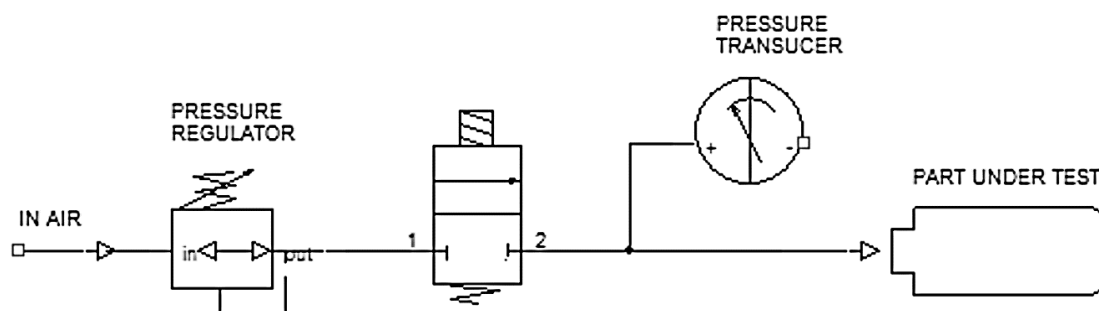


Figure 4: absolute system

3.2 Flow System

Air leak testing allows direct measurement of the flow or air flow produced by the leak.

At the end of the filling and adjustment phases, the test time is the time required to obtain a stable measurement of this flow rate, which is usually very short (e.g., 100...300 ms) [2].

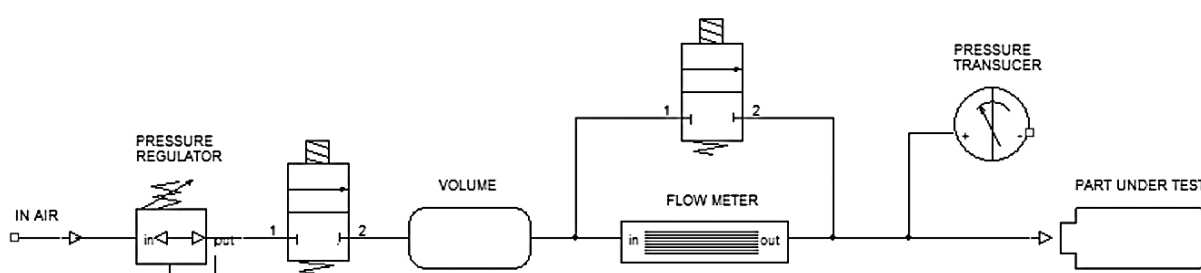


Figure 5: Flow System

As pointed out in the figure, the measure of this flow depends on the differential transducer which can read the pressure drop through a load leak.

To reduce the quadratic tendency caused by the turbulent motion of the gas particles, a laminar element is used which can make this function partially linear. ($\Delta p / \text{Flow}$).

As an alternative to the volumetric flow measurement (precisely with the Δp measurement), in the last ten years the application of the mass flow meter has become much more used, for example the thermal system or the flow meters (hot-wire system), because they are much more accurate, constant over time, easily available on several scales and less sensitive to the thermal variation of the gas to be measured.

3.3 The Advantages of this Method

- **Continuous measure of the leak**

This is the actual reason why this principle is still applied in the industrial field. In a natural way, that is without any artifice, with this system a leakage can be analysed over a given period, allowing the operator to find it and repair it in real time during the measurement.

- **Duration of the testing phase practically zero**

The flow measurement being a continuous type of measurement, it allows the elimination of a real time synchronization of the test. This concept must

be considered in a strictly theoretical way, because if in a drop or Δp systems the regulation or testing phases can be partially overlapped, with this method, the measurement must necessarily be made in the best adjustment conditions.

- **Leak indication in volumetric units (CC/time)**

This feature must be kept between benefits. Conversely, compared to other systems, this principle has some disadvantages; the first and most obvious results from the complexity and instability of flow measurement.

In addition to the cost of a double measurement process (of both pressure and flow) and then a double control needed to obtain the full validation of the measure, the laminar element - which is practically like a capillary - is hardly influenced by dirt or distortion.

The measure must be checked constantly with reference nozzles, which, as micropores on a ceramic or metal base, tend to deteriorate and then have a limited duration. Any parasite leakage before the flow measuring element may lead to a misleading outcome and mask the possible leakage of the tested part.

This method is suitable in the following situations:

- When the volume of the piece is not known and it is variable: for example, very flexible packages or bottles;
- When the test times must be reduced at most;

3.4 Mass Flow Leak Test

The Mass Flow test measures flow rate through an object. Once the object is attached to the test port it is pressurized with regulated air.

The test pressure is compared to the programmed tolerance using a pressure sensor. During the test, the flow is measured with a Mass Flow Sensor. Objects that have a flow rate that falls between the maximum flow value and the minimum flow value pass while those that do not, fail [3].

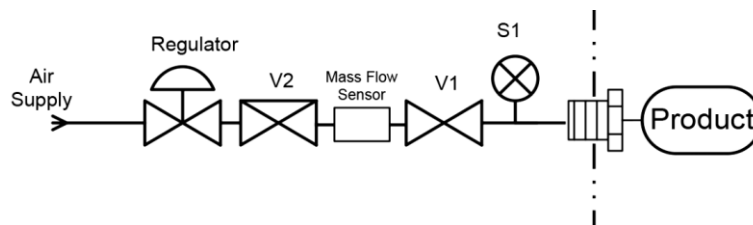


Figure 6: Mass Flow test

How it works:

1. The product is attached to the test port and the test sequence is initiated.
2. The **Fill** step, pressurizes the part with regulated air. The test pressure is measured to the programmed tolerances using the pressure sensor.
3. During the **Test** step the measurement of flow is taken by the Mass Flow Sensor.
4. The flow reading to the max and min flow values is compared to determine a pass or fail. The flow reading and test result are displayed on the test screen and the pass or fail light are illuminated.

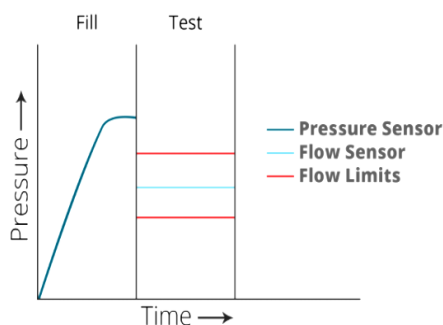


Figure 7: Test result

Differential system

The differential system (figure 8) is used in those cases where it is necessary to have the same sensitivity to very different pressures.

Until a few decades ago, the measurement of leaks through the differential pneumatic circuit has been the most ingenious artifice used in this field to remedy the poor accuracy of the measurement and electronic acquisition sections until then.

Two pressure sensors are used in a differential air decay test along with a test and reference part. One sensor measures the test pressure and a second sensor measures the differential pressure drop from a leak.

The filling phase was made by opening both valves. The settling phase was done with the valve B closed, and the valve A opened, in order to stabilize and standardize pressure conditions into two branches. At the end of the settling phase, all the valves were closed. The pressure is equalized on both sides of the differential pressure sensor during the fill and stabilize steps. The test step isolates the leak as a differential pressure drop over time multiplied by the part's volume.

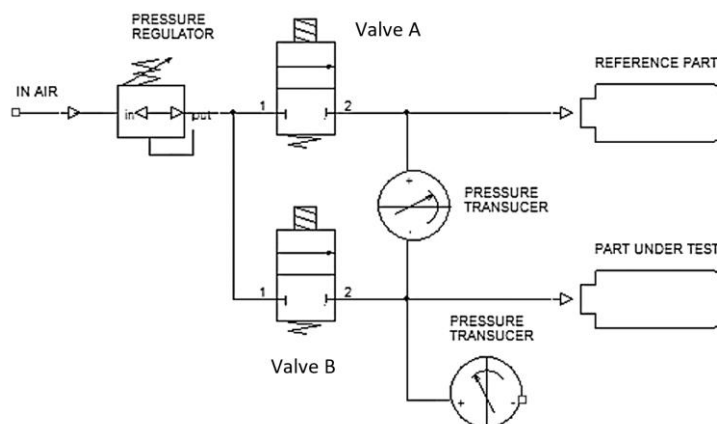


Figure 8: Differential system

Possible pressure drop in the test piece moves the zero of this measure, allowing a very sensitive

indication of this deviation. On this principle, one can make an easy electrical amplification of the signal

coming from the transducer, and view it on a device with a central zero needle. This artifice permitted to analyse a value of typical decay of 1/50.000 (transducers allowing) at the value of the filling pressure, while the electronic of those times, if it was applied in a pressure gauge system it did not allow to overcome the ratio of 1 / 10.000. This transducer had to be rated for the maximum filling pressure, because in case of leakage of the testing piece, the membrane was solicited by the total pressure [4].

A differential pressure decay test is best suited for testing leaks that have a pressure drop per second larger than the accuracy of the differential pressure sensor and greater than 0.03 mbar/second (3Pa/s). For example, a 0.05 mbar (50 Pa) differential pressure sensor with accuracy of 2% of reading +1% of full-scale, could be used to test a 2 sccm max. leak from a 1-liter part, 0.033 mbar/seconds (3.3 Pa/s). Measuring the leak as a pressure drop for 2 seconds would cause a 0.067 mbar (6.7 Pa) pressure drop that is >10 times the sensor's accuracy.

The system made in this way has several disadvantages:

- The comparison examines a tight reference: if this reference has a leak, it coincides with a "masking" of the actual leakage of the tested part. This defect was repaired by a continuous check of the system in use by a "good" sample and the electrical calibration of the "Zero" measurement.

- Difficulties in calibrating the differential transducer measurement, which had to be performed with a special verification procedure.

- The leakage measurement that was made seems to be a measure that does not indicate the actual leakage of the tested part, but the relative difference with the sample.

- This does not necessarily coincide with the concept that the reference sample can leak (that also corresponds to reality). The sample piece is mechanically stressed at every testing cycle, while the part that is being tested only during the phase of its own test.

It will analyse a trend of measured decay that progresses with the hours of use of the system, an index of progressive mechanical adjustment of the reference sample that does not coincide with the adjustment of the tested parts.

The drawbacks of the differential system are:

- It is pneumatically complex
- It requires a double pressure measurement section (filling and testing)
- Lower measurement repeatability
- Longer test times
- Major instrumentation costs

Direct Mass Flow vs. Differential Mass Flow Tests

Testing parts for a leak using mass flow technology requires a sensitive flow meter capable of sensing very small changes in flow rate. The flow meter should have minimal resistance to flow so that it does not require a large pressure drop in the part to overcome the resistance of the meter. The flow meter needs a high enough range so that it would not reach overflow conditions during the transition from bypass flow (fill cycle) to direct flow (test cycle). The air supply for the mass flow test must be clean and dry. The test air flows through the flow meter for each test. The flow meter typically has a very small flow path; therefore, it is susceptible to contamination. Most flow meters use a thermal transfer method of measuring air flow and, consequently depend on the specific heat factor of the air. Moisture in air affects the specific heat factor of the air. Therefore, it is important for consistency to have dry air.

The most important aspect of a reliable and accurate flow test is to have a reliable and constant supply pressure for the test. The simplest mass flow circuit would be direct mass flow. For direct mass flow, a regulator or a constant pressure source supplies air directly to a flow meter that is connected to a test part. Additional valves to bypass the flow meter to quickly fill the part prove to be very useful. Below is an example of a Direct Mass Flow circuit.

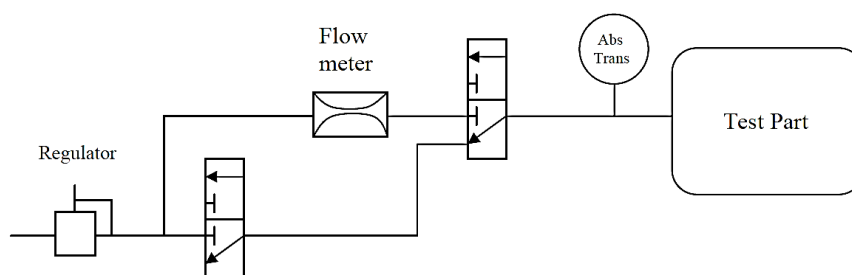


Figure 9: Direct Mass Flow circuit

For a direct mass flow test, let us assume that the reference pressure provided by the regulator is constant to a factor 30 to 100 times better than the possible pressure loss generated in the test part because of the expected reject leak rate. For instance,

if a test part with a volume of 1000 cc has a leak rate of 1 sccm during a test time of 20 seconds, the part will lose 0.005 psi or 0.00025 psi/sec. This pressure loss differential of 0.005 psi as compared to the reference pressure causes a flow through the flow

meter of 1 sccm. It is the loss of 0.00025 psi/sec that will generate a 1sccm flow output signal. This assumes that the reference pressure has a variation less than 0.000005 psi/sec during the test cycle.

Since a mass flow test result is simply the final flow reading at the end of a sequence of timers, the actual flow result and the repeatability of multiple flow tests depend on how well the regulator can maintain a very constant pressure through the test sequence. Within a plant environment, this condition is difficult to be met.

Therefore, the smaller the leak rate or the smaller the pressure change generated by the leak in the test part, the more critical the control of the reference pressure becomes.

There are two approaches to control the reference pressure.

Direct Mass Flow Measurement

To use the direct mass flow approach, the biggest problem is the use of fluctuating factory air cyclically and instantaneously throughout the factory. For good results, additional equipment must be used between the air supply to the installation and the mass flow instrument. The added equipment usually includes a series of precision regulators and a tank which has a volume ten times larger than that of the piece. Each of the regulators reduce the plant air pressure by 5 to 10 psi next to the regulator or the accumulator tank. The direct mass flow instrument then takes its supply air from the accumulator tank through a final precision regulator to the mass flow meter. This series of regulators and accumulation tank filter reduce or eliminate the pressure turbulence of the plant air supply and create a stable reference pressure for a direct mass flow test (figure 10).

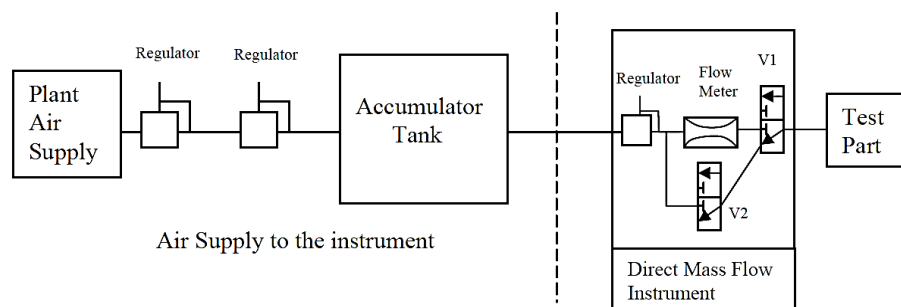


Figure 10: Direct Mass Flow Measurement

The direct mass flow approach measures the rate of air flow going to the part that makes up for the air that is leaving the part (leak rate) plus any pressure effects for changing temperature or volume in the part or parts test circuit. To get a true leak rate measurement there must be enough stabilization time for all or most of the temperature and/or volume changes in the part to normalize before taking this final instantaneous flow reading. Because this method of measurement assumes that the supply pressure is infinite and constant, the flow reading of the flow meter directly equals the leak rate of the part.

Differential Mass Flow Measurement

Another approach to achieve a stable reference pressure for mass flow testing is the Differential Mass Flow Method. Two pressure sensors are used in a differential mass flow test along with a test and reference part. One sensor measures the test pressure and a second sensor measures the air moving through the mass flow sensor or Laminar Flow Element (LFE). For this method, the stable reference pressure for the mass flow test is provided by using a reference part within the test circuit and measuring the relative flow between the reference part and the test part through a flow meter as a result of a leak in the test part [5].

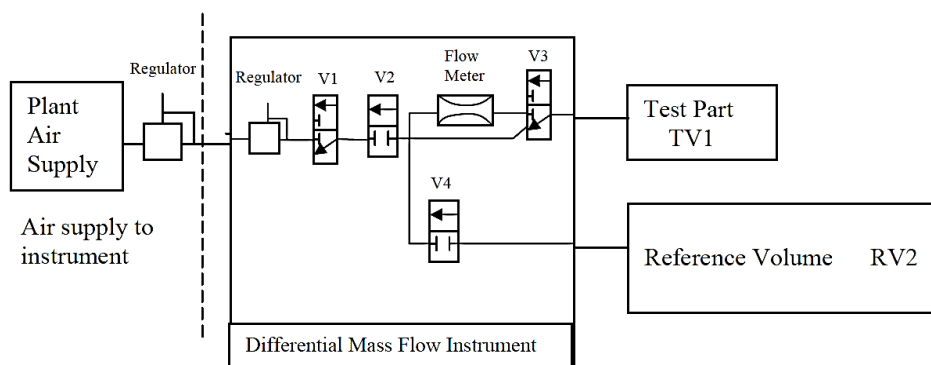


Figure 11: Differential Mass Flow Measurement

For the differential mass flow instrument, plant air fills both the Test Part and a Reference Volume for each test. After pressurizing these two volumes, they are isolated from the plant source air by switching the fill/exhaust valve (V1) and closing the isolation valve (V2) to allow the volumes to stabilize in pressure to each other. After a suitable stabilization time, the flow select valve (V3) is activated to connect the two volumes via the flow meter.

After additional stabilization time where the overall volume of V1 plus V2 are connected together through the flow meter, a final flow reading is taken of the air transferring for the Reference Volume (RV2) to the Test Part (TV1). During this final phase of the leak test, the Test Part (TV1) and the Reference Volume (RV2) act as one volume (TV1+RV2) from which a leak is measured. Therefore, when there is a leak in the Test Part, the pressure in the overall volume (TV1+RV2) decays.

The flow measured by the flow meter is the air transferred from the Reference Volume to the Test Part and does not directly represent the air flow from the leak in the Test Part. The air flow measured by the flow meter is proportional to the Leak Rate based on the ratio of the Reference Volume (RV2) and the Total Volume (TV1+RV2), where the Leak Rate = Flow meter reading x (TV1+RV2)/RV2, if sufficient stabilization time is given to reduce any temperature or volume change effects.

The differential mass flow systems must be calibrated in some way to determine the ratio of these volumes so that an accurate representation of the leak rate can be measured. For small leak rate applications, it is desirable to have a Reference Volume that is significantly larger than the Test Part volume so that measured flow rate of the flow meter is close to the actual leak rate.

4. Conclusion

The growing demand for components and systems with fewer acceptable losses has become a trend in the industry, because of several compelling market demands, such as economic requirements, environmental protection specifications, safety constraints and quality products requirement.

The end result is stricter quality controls for leak testing. Researchers, technicians, scientists, producers etc., working with hermetically closed elements and vessels, vacuum or only tight seals have to become familiar with measurements and location of leaks.

Remarkably, this technical field is nearly unknown even in engineering and can be an important project in organizations. Every methodology has advantages and disadvantages; to be able to make a right choice, one must balance them the production requirements.

For the choice of the test methodology that will be used, it is necessary to accurately consider all admitted leak limits and all the other factors, not only the technological requirements, but also the corporate image, regulation developments and the new requirements of the market.

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