The differential-pressure air permeability test for use in the nonwovens, filter, and paper industries

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ABSTRACT: This paper will provide present and potential uses of the differential-pressure air permeability tester. Nonwovens are increasingly blurring the traditional understanding of paper and textiles. Nonwovens are so versatile that the same product, with only minor modifications in fabrication, can be used in both paper and textile applications. This is especially apparent in the filter and disposable textile industries. As a result, filter and textile testing instruments are in increasing demand for the nonwovens and paper industry in general. This paper discusses the differential-pressure air permeability instrument and its associated uses. It covers the history and function of the instrument, and also recounts how permeability can be related to many other characteristics of a material. The permeability instrument can be used to enhance acceptance testing, quality control, and research processes.

KEYWORDS: Air permeability, instruments, nondestructive tests, pressure gradient.

Discussion

Origin of the differential-pressure air permeability instrument

There are many methods and types of instruments that are used to measure permeability. They range from the simple and unsophisticated, such as by blowing through a sample by mouth, to expensive, elaborate, computer-augmented models.

In the early 1940s, the National Bureau of Standards (NBS), now the National Institute of Standards and Technology (NIST), saw the need for an instrument that would reliably, accurately, and repeatedly measure the permeability of textile-like fabrics. An instrument was developed at that time by the NBS *(1)*. Several companies including the Frazier Co. continue to make this instrument or similar clones of it. The major differences in these clones are the procedures used to calibrate them.

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The NBS instrument is technically known as a differential-pressure air permeability tester and is the principal type of permeability instrument considered here. Its distinguishing feature is that it measures the permeability of a sample at a controlled differential pressure across the sample as a reference.

Some other past and present permeability testers, in addition to those using the mouth method, operate by (a) measuring the relative difference of air a blower can force through a sample, (b) making a timed measurement of passing a predetermined volume of air under a constant pressure through a sample, (c) using a piston to force air through a sample, and (d) using a transducer/computer combination to calculate airflow.

How differential-pressure air permeability instruments function

The original NBS instrument functioned by setting a differential pressure in inches of water (usually 0.5 in.) across a sample and measuring the airflow in cubic feet per minute (cfm) at that differential pressure with a calibrated venturi nozzle in an orifice plate type of arrangement.

The differential pressure across the sample is measured in the NBS instrument by an oil-filled manometer that reads in inches of water. This reading is achieved by controlling the speed of a suction blower by hand/eye coordination. Other instruments achieve similar results by an adjustable spring-loaded poppet valve, gauges, or electronic sensors. The airflow through the NBS instrument is measured by means of a second differential pressure, shown in a second oil manometer, across a series of calibrated venturi nozzles. Other similar instruments read airflow by gauges, such as electronic sensors augmented by computers or other flow sensors.

Adjustment and calibration

The calibration procedure of the differential-pressure air permeability instrument by the Frazier Instrument Co. is a unique two-step process. It features an additional procedure that allows the operator to perform a self-diagnosis to determine the instrument's operational and calibration states.

The first step consists of a pre-calibration check and adjustment of the instrument by Frazier to ensure that each instrument performs similarly to other Frazier instruments. The second calibration step closely follows the original NBS calibration procedure but has been modified slightly to make theoretical procedures agree with actual results. The Frazier Co. is now uniquely able to effect a calibration similar to the NBS procedure; our procedure is now a proprietary process.

This calibration procedure includes timing the flow of a given volume of air passing through the nozzles, taking certain environmental measurements to determine air density at the time of calibration (to reduce the data to standard conditions), and producing a calibration chart. This chart gives the airflow in cubic feet per minute per square foot of sample for each nozzle that is equivalent to each inch of oil in the manometer.

The major part of calibrating an instrument lies in the unique configuration of its individual venturi nozzles. However, a significant portion of this calibration lies in the unique turbulence patterns of the airflow through the instrument. This flow pattern can contribute 5–10% of an instrument's calibration. A summary of the calibration procedure can be found in ASTM Standard F778 *(2)*.

I. A comparison of the Frazier high-pressure air permeability instrument to the Frazier mercury manometer retrofit using "calendered pet" airbag material from Hoechst Celanese, Charlotte, NC

	Frazier standard high-pressure air permeability instrument with 21-in. H_2O diff. pressure range		*Mercury manometer with air permeability retrofit with 410-in. H_2O diff. pressure range*	
Orifice size, mm	*Diff. pressure, in. H_2O*	*Airflow, cfm*	*Diff. pressure, in. H_2O*	*Airflow, cfm*
1.0	0.5	0.337	0.5	0.337
1.0	1.0	0.816	1.0	0.765
1.0	2.0	1.56	2.0	1.54
1.4	4.0	3.07	4.0	2.96
2.0	7.0	5.15	7.0	5.02
2.0	10.0	7.25	10.0	7.06
2.0	15.0	10.5	15.0	10.4
3.0	20.0	13.4	20.0	13.5

II. Air permeability results comparing "calendered pet" airbag material from Hoechst Celanese to a dense-coated cardboard material using the Frazier air permeability retrofit

	Calendered pet		*Dense-coated cardboard catalog cover*	
Diff. pressure, in. H_2O	*Orifice size, mm*	*Airflow, cfm*	*Orifice size, mm*	*Airflow, cfm*
0.5	1.0	0.337	1.0	0.0
1.0	1.0	0.765	1.0	0.0
2.0	1.0	1.54	1.0	0.0
4.0	1.4	2.96	1.0	0.0
7.0	2.0	5.02	1.0	0.0
10	2.0	7.06	1.0	0.0
15	2.0	10.4	1.0	0.0
20	3.0	13.5	1.0	0.0
30	4.0	19.0	1.0	0.0
40	4.0	24.8	1.0	0.0
50	4.0	30.4	1.0	0.057
60	4.0	36.0	1.0	0.085
70	4.0	41.3	1.0	0.113
80	4.0	46.6	1.0	0.169
90	4.0	51.9	1.0	0.225
100	6.0	54.7	1.0	0.281
120	6.0	61.4	1.0	0.393
140	6.0	69.6	1.0	0.561
160	6.0	79.6	1.0	0.638
180	6.0	90.1	1.0	0.740
200	6.0	99.9	1.0	0.836
225	6.0	114	1.0	0.959
250	8.0	129	1.0	1.11
277	8.0	150	1.0	1.27
300	8.0	179	1.0	1.40
350	-	-	1.0	1.71

The self-diagnosis available to operators of the differential-pressure air permeability instruments consists of test plates, which simulate unchanging test samples. The major part of calibrating a venturi nozzle instrument is intrinsic to the nozzles; the calibration cannot be made by an operator. The test plates only ascertain the performance of the instrument or venturi nozzles.

Test plates can be used to certify that the instrument is operational or that the individual nozzles are within calibration parameters as demanded by calibration authorities such as the ISO 9000 series of standards or Military

Standard 1157 *(3)*. TAPPI Test Method T251 cm-85 *(4)* is somewhat misleading on this point in its paragraph A.2. Orifice-type permeability instruments equipped with manometers as described in the appendix cannot be calibrated by the operator. Systems involving manometers cannot be adjusted to change calibration.

The "calibration" plate described in paragraph A.2 should more properly be termed a "calibration test plate." Paragraph A.3 describes a system equipped with gauges in place of manometers, and a means of calibrating gauges as described in paragraph A.3 is necessary. Neither of the orifice-type instrument systems described in the appendix permits the operators to calibrate or adjust the orifices. The "calibration" procedure only acts to discover the intrinsic calibration of the orifices. (See "Test plates and calibration" in the appendix.)

Evolution

Permeability is used today in the paper, nonwovens, and textile industries to characterize important attributes and changes in those attributes.

Permeability in textiles was originally measured to provide an objective measure of the breathability of clothing. It was a means of evaluating whether a fabric would make a "cool" or "warm" garment. The measuring instrument indicated the relative ease with which air could pass through the fabric. Over the years, textile manufacturers recognized that the differential-pressure air permeability test was extremely sensitive and repeatable. They found that it was a quick, convenient, nondestructive test for determining differences in the quality of a given fabric. The test did not specify what changes had occurred, but it was an accurate, reliable indicator that changes had occurred. These changes can include tightness, additives, calendering, thickness, and arrangement of fibers in paper and nonwovens.

Acceptance testing/production quality control

Acceptance testing and internal quality control in the production process are the two major uses of the differential-pressure air permeability tester. Although most instrument users are not interested in the actual permeability of a product, they are attempting to discern changes in that product or variability in its production process. The accuracy and repeatability of the test added to the simplicity, quickness, and relatively low cost have made it one of the most useful methods for characterizing materials with some degree of voids at a microscopic level. It is the changing of the size and shape of these microscopic voids that causes changes in permeability. In addition, since it is a nondestructive test, the instrument can be used to test 100% of a production run.

The permeability test is equally useful in research. Each material can have a range of acceptability characterized by more elaborate test methods. Many times these characteristics can then be directly related to physical changes affecting permeability.

For example, the air permeability test is often substituted for time-consuming and expensive liquid permeability tests. Although there is no general correlation between liquid and air permeability tests, a close correlation between the two tests can often be established for each type of material. The air permeability test is nondestructive whereas the liquid test may not be. In the filter industry, these tests on paper or other nonwovens and textiles are also direct tests for permeability.

Latest research

Until recently most differential-pressure permeability air tests have been limited to differential pressures less than 508 mm (20 in.) H_2O. For most papers, a differential pressure of 127–254 mm (5–10 in.) H_2O is necessary to obtain a usable reading. For example, at the customary standard 12.7 mm (0.5 in.) H_2O differential pressure, permeability cannot be obtained for bond paper. However, at about 127 mm (5 in.) H_2O differential pressure, different grades of bond paper can be characterized. Furthermore, an operator can also locate the permeability differences through the watermark of that bond paper by simply moving the sample in the clamp holder and observing the resulting permeability changes.

Last year the Airbag Subcommittee of ASTM D13 initiated a search for a method to determine the permeability of very dense materials, such as coated and uncoated passenger car airbags. In response, Frazier Instrument developed an optional retrofit for its high-pressure permeability instrument that would allow testing at very high differential pressures. Differential pressures up to approximately 7 m (276 in.) H_2O were demonstrated using coated cardboard and calendered airbag material. This new development now allows the differential-pressure air permeability testing of practically all ranges of papers and nonwovens as well as airbags.

Major advantages and disadvantages of differential-pressure air permeability testing

The major difficulties in using the differential-pressure air permeability test include sealing samples to prevent edge leakage and possible oil overflows when used carelessly. Furthermore, air density adjustments are necessary when test instruments are more than 610 m (2000 ft) apart in altitude.

An advantage of using the differential-pressure air permeability test is that it is inexpensive; skilled operators and elaborate equipment are not needed. Furthermore, the test is simple, accurate, repeatable, and reliable. Adjustment is usually not required for changes in atmospheric density, and a great range of materials—paper, nonwovens, textiles, and porous metals—can be tested.

Summary

The differential-pressure air permeability tester is a simple, inexpensive instrument for acceptance testing, quality control, and research. It provides a nondestructive test that is fast, accurate, repeatable, and extremely versatile. The instrument's most outstanding feature is that it can predict physical properties or changes in properties such as tightness, additives, calendering, thickness, and arrangements of fibers

Literature cited

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2. ASTM F778 "Standard methods for gas flow resistance testing of filtration media."
3. Mil. Std. 1157 "Military standard calibration and calibration verification procedures for textile test methods—Method 5450."
4. TAPPI T 251 cm-85 "Air permeability of porous paper, fabrics, and pulp handsheets."

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Appendix

Test plates and calibration

Because of our customers' increasing needs to check the calibration of their Frazier differential-pressure air permeability machines, the company has produced a series of test plates for this purpose.

The calibration of the machines is based on calibrating the venturi nozzles that are used to measure airflow. Once each of the nozzles is calibrated, that calibration is permanent and is not affected by use of the instrument. Only physical abuse of the nozzles can affect their calibration.

The instrument can malfunction through abuse or age. Some conditions that can cause a malfunction include oil in the system, air leaks in the system, aged or improper oil, improper leveling, obstructions in the system, and malfunction of the electrical components. Each of these items is easily repairable by the owner.

The standard test plate provided with each instrument should be used regularly to check the system. However, it cannot be used to adjust the instrument or affect the calibration that is intrinsic to the nozzles and set by the company. The test plates function by simulating a relatively unchanging test sample.

As a general guide, a reading obtained when a test plate is used should be within plus or minus 3% of the test plate calibration. However, a variation within 2% is preferred. Furthermore, a variation in readings of about 1.0% due to changes in atmospheric density is normal. A discrepancy of more than 5% is usually unacceptable.

Variations of ± 5% can occur when the nozzle is not calibrated in the instrument in which it is to be used. This is especially true when a nozzle is used in a nonstandard instrument or when a test plate is used to check instruments made by other companies.

The standard test plate can also be used to check the calibration of the nozzle, which is one of the nine standard calibrated venturi nozzles supplied with the instrument. Because the standard test plate supplied with the instrument can only be used in conjunction with the 4-mm nozzle and because of the more demanding needs of some researchers, a special series of test plates is available; these plates can check the calibration of the other eight nozzles that are standard with the instrument. These test plates cannot be used to adjust the instrument or calibrate the nozzles.

An improved permeability tester

At the October 1991 meeting of the ASTM D-13 Subcommittee on Inflatable Restraints, the Frazier Co. was asked to design an instrument that would extend the differential-pressure range to approximately 10 psi (276 in. H_2O). This would allow air permeability testing of the very dense or coated materials, such as those used in passenger car airbags. This would eliminate the problem of obtaining a readable airflow from very dense or coated materials at the lower differential pressures now attainable.

A relatively inexpensive optional retrofit for the high-pressure air permeability instrument has been developed. This option provides the same repeatability and reliability as the instruments presently used.

A potential problem with a retrofit is that it may cause a significant change in the turbulence patterns of air passing through the instrument. Excessive turbulence can act as a variable restriction, and any changes in air turbulence patterns through a permeability instrument can significantly affect its performance.

Table I shows that, at lower airflows (using up to a 6-mm-diam. nozzle), the turbulence generated by the retrofit does not affect the operation of the instrument. The repeatability demonstrated between our master instrument and a new, retrofited high-pressure instrument is well within acceptable levels up to 20 in. H_2O and about 80 ft^3/min airflow. It is expected that the very dense materials used in airbags will produce airflows nearly as high as 80 ft^3/min.

Table II shows that the instrument with retrofit can indeed operate at a differential pressure over 270 in H_2O with good repeatability. The right manometer of the instrument still indicates the actual amount of air flowing through the nozzle at a given differential pressure.

Using a mercury manometer reading in inches of water to indicate differential pressure rather than using a 300-in.-high red oil manometer raises one other potential problem— the possibility of increased error in reading the manometer. The oil manometer of the standard instrument breaks down the differential pressure readings into increments as small as 0.001 in H_2O with the expanded (inclined) scale. However, the mercury manometer necessary to attain up to 300 in. H_2O differential pressure cannot reliably read closer than about 0.5 in. H_2O differential pressure. However, this should not be a great handicap, because the much greater differential pressures involved should effectively act to characterize the samples.

The new retrofit promises to be an efficient means of checking the permeability of dense materials, and it also appears to be a relatively effective process that does not require the purchase of additional expensive equipment.