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New testing device for air permeability

Lilia Sabantina[1,2], Andrea Ehrmann[2,*]

[1]*Berlin School of Culture and Design, Hochschule für Technik und Wirtschaft Berlin – University of Applied Sciences (HTW Berlin), Berlin, Germany*
[2]*Faculty of Engineering and Mathematics, Bielefeld University of Applied Sciences, Bielefeld, Germany*
*Corresponding author *E-mail address:* andrea.ehrmann@fh-bielefeld.de

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ABSTRACT

Air permeability is used to characterize textile fabrics with respect to their usability as a garment or filter, airbag or parachute. It depends on the fabric's porosity, air voids in the fabric, yarn specifications, thickness and other parameters, making it hard to calculate it reliably from other parameters. At the same time, measuring air permeability requires relatively expensive and complex equipment that cannot simply be built by everybody. Here, we suggest a simple device, which can be built from inexpensive components and correlates air permeability to a time measurement. We show that these values are highly correlated with the results gained by the frequently used standard EN ISO 9237.

Keywords
testing device,
air permeability,
air flow,
EN ISO 9237

1 Introduction

The air permeability of textile fabrics was identified very early as an important parameter for wearing comfort, but also for the usability of technical textiles [1]. A few of the early test devices were based on the falling cylinder principle, measuring the time that a falling cylinder needed to pull a defined air volume through a fabric of defined area [2]. Several former and most recent instruments, however, measure the air permeability of a fabric by calculating the air flow through a textile fabric of defined area in a defined time, if a given pressure (e.g. 100 Pa) is applied [3-5]. These tests are described in several standards, such as ASTM D737-75 (Standard Test Method for Air Permeability of Textile Fabrics), ASTM F778-82 (Standard Methods for Gas Flow Resistance Testing of Filtration Media), or EN ISO 9237 (Textiles – Determination of Permeability of Fabrics to Air).

In recent literature, tests based on these standards or similar approaches are generally described. Tang et al. used air permeability measurements according to ISO 9237 to find a correlation with sound absorption coefficients of textile fabrics, measuring the air flow through the fabrics at a defined pressure [6]. Similarly, Kim et al. used Pitot tube pressure sensors to investigate the differential pressure before and after a textile fabric [7]. Khalil et al. investigated the air permeability of cotton single jersey knitted fabrics according to EN ISO 9237, again detecting the air flow through a textile for a specific pressure drop, compared to relative water vapor permeability and other parameters [8]. With a similar setup, Sakthivel and Senthil Kumar measured the air permeability of recycled polyester/cotton nonwovens according to ASTM D737 and correlated them with sound absorption characteristics [9]. In the same way, other researchers used methods in which either pressure or air flow was measured, while the other parameter was kept constant, either directly based on one of the aforementioned standards or using analogous setups, resulting in correlations between air flow through a fabric and pressure drop.

These tests are usually reliable and reproducible, but not affordable for everyone, nor can they simply be built from inexpensive equipment. Thus, some suggestions based on a different principle were patented. Kawabata mentioned a falling piston that presses the air through a tested specimen and using the built-up pressure to measure the air permeability [10]. Similarly, Wang et al. [11] as well as Wagner and Cain [12] suggested using gravity as the force driving the moving part against the air pressure built in a chamber closed by a textile fabric under investigation, while Lyu et al. described a similar apparatus building up pressure with a pump [13]. Such systems, however, are scarcely found in literature, probably because – compared to highly automated systems according to EN ISO 9237 or similar standards that are nowadays available – their inexpensive setup goes along with a more complicated and time-consuming handling during the tests. Nevertheless, the mentioned patents are based on the simple physical idea that reducing the amount of air flowing through the textile under examination will reduce the speed of the falling piston, making this sort of test instruments also useful for measuring air permeability of textile fabrics. It must be mentioned, however, that neither a linear correlation between the inverse falling time in these apparatus and the air flow according to ISO 9237 etc. can necessarily be expected, nor is it fully clear from literature which influence the friction between the falling piston and the surrounding tube will have.

Here, we thus describe a possible test device according to the falling cylinder principle that is built easily, does not need any expensive components and shows results in good agreement with those gained by a commercial air permeability tester according to EN ISO 9237. We discuss potential reasons for reduced reproducibility in this kind of testing device and explain the advantages and limits of the apparatus described here, especially in terms of automation of the test procedure for fabrics with very high or very low air permeability, respectively.

2 Materials and Methods

Fig. 1 depicts the overall construction in upright (Fig. 1a) and rotated position (Fig. 1b), which will subsequently be discussed in detail. Generally, a translucent tube (inner diameter 94 mm) has a clamping device at one end (upper end in Fig. 1a) in which a textile fabric can be clamped; the other end is open. The inner diameter should exceed the testing area, but not be too large to avoid potential bending of the tube, which is why this value was chosen. The measuring cross-section is a round area of 10 cm², as it is also specified in EN ISO 9237. An electromagnet holds a piston (mass 2272 g, height 77 mm, diameter 94 mm, made from stainless steel with an open area inside enabling the addition of more weights), which can be introduced into the tube in a position similar to Fig. 1b. Rotating the tube back into the upright position, the electromagnet can be switched off, allowing the piston to fall freely inside the tube. Friction between tube and piston is reduced by spraying the inner side of the piston with a lubricant (Ballistol oil); this is necessary approximately after each tenth test run. The whole system was built for less than 250 €, as compared to commercial testers according to ISO 9237 that cost approx. 2 orders of magnitude more.

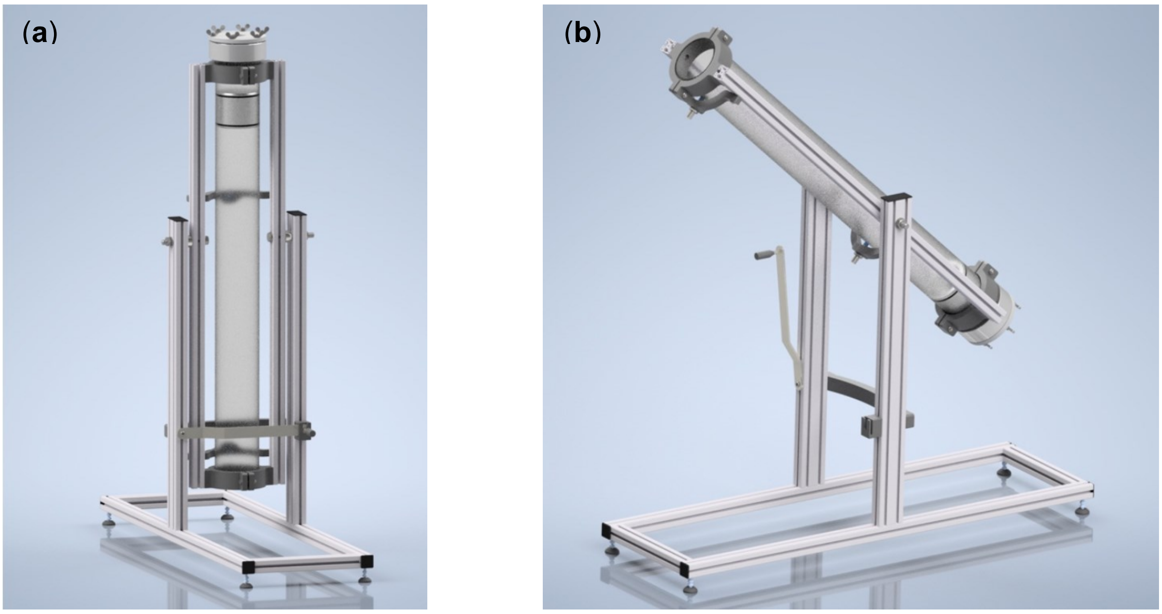

Fig. 1 Air permeability tester: (a) upright position (textile on top); (b) rotated position enabling insertion of the falling cylinder.

Gaskets on upper and lower ends of the piston (cf. black rings around the piston in Fig. 1a) as well as between clamping disk and tube ensure that air can only be drawn into the increasing volume above the falling piston through the clamped textile. This means that the piston speed is lowered by the reduced pressure above the piston, and that a fabric with higher air permeability will speed up the pressure compensation and thus allow the piston to fall faster than a textile with lower air permeability. If the falling time is too long, up to six additional weights (232 g each) can be added to the piston (2272 g), with each additional weight in the form of a disk with screw thread in the middle, allowing to fix them on a screw in the hollow inner part of the piston, so that with all six additional weights, the inner part of the piston is filled. For a comparison of measurements with different additional weights, a calibration table can be used, similar to the comparison between different shore-hardness values.

The falling time of the piston is measured by two inductive sensors, mounted in the semi-circular black parts behind the tube visible in Fig. 1a. By starting the measurement 40 cm below the piston's initial position, the acceleration phase at the beginning of the motion is neglected. The sensors are connected with a Raspberry Pi 4, which also controls the display showing the falling time.

For the tests reported here, 8 different textile fabrics were examined:

Table 1. Fabrics under examination.

Sample name	Textile material	Weave construction	Thickness / mm
PES1	Polyester	Satin	0.53
PES2	Polyester	Plain weave	0.31
WO	Wool	Plain weave	0.82
BA	Bamboo	Woven fabric	1.20
VI	Viscose	Twill	0.20
LI	Linen	Plain weave	0.33
JU	Jute	Plain weave	1.02
VV	Synthetic fibers	Velvet	1.07

For the comparison with measurements according to EN ISO 9237, an FX 3300 Lab Air IV testing instrument (Textest AG, Schwerzenbach, Switzerland) was used. Tests with the custom-made instrument were performed 11-27 times per sample; tests with the FX 3300 Lab Air IV were performed five times per sample.

3 Results

The results of the comparison between both test procedures are depicted in Fig. 2. For the tests, 2-6 additional weights were added to the piston. Comparing measurements of identical samples with different numbers of additional weights (PES1, PES2, LI and JU), measurements with 2 additional weights always lead to higher falling time than the comparable measurements with 3 additional weights (in case of PES1, LI and JU). The differences are 53%, 83% and 50% for PES1, LI and JU, respectively. While the first and the last value are very similar, the middle value for the LI sample differs clearly from them. This already shows that the aforementioned possibility to create a calibration table for the comparison of measurements with different additional weights may become less straightforward than hoped for. These deviations may be explained by different stretchabilities of the fabrics, i.e. fabrics with higher stretchability may be influenced more strongly by the underpressure below them, leading to larger pore sizes. Nevertheless, it must be mentioned that for sample PES2, measurements with 3 and 6 additional weights resulted in approx. identical falling times, suggesting that the impact of the additional weight will saturate at high masses.

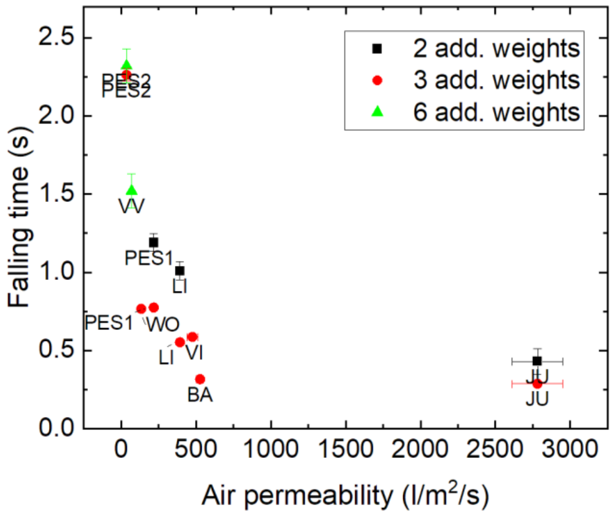

Fig. 2 Correlation of falling time in the gravity-driven tester and air permeability measured according to EN ISO 9237.

Another important point is the variation of nominally identical measurements, i.e. the reproducibility. In the graph, most results show only very small error bars, with larger standard deviations only being visible for JU, PES2 and VI. Comparing the test results, the measurements according to EN ISO 9237 had relative standard deviations between 0.9% (VV) and 8% (VI), with an average of 2.8%. All relative standard deviations are depicted in Table 2. For the measurements with 3 additional weights, standard deviations between 0.8% (WO) and 7% (BA) were measured, with an average of 2.3%. Except for bamboo, standard deviations are always larger for the commercial tester. These results show that the custom-made instrument has a reproducibility similar to the value of the commercial instrument.

Table 2. Relative standard deviations for both measurement methods.

Sample name	**Relative standard deviation / %**	
	EN ISO 9237	Gravity-driven custom-made tester (3 additional weights)
PES1	3.7	1.6
PES2	2.7	1.8
WO	3.2	0.8
BA	1.5	7.2
VI	7.8	1.8
LI	2.1	1.6
JU	6.1	1.0
VV	0.9	-

Since the falling time in the newly developed device is smaller for larger air permeability, with a measured falling duration of 0.22 s if the instrument is used without textile, it should be tested whether the measurement results show an inversely proportional correlation. Fig. 3a depicts this correlation, while a semi-logarithmic correlation of the same data is plotted in Fig. 3b. While no linear correlation is visible (Fig. 3a), a semi-logarithmic correlation is possible (Fig. 3b), but needs more detailed test series to investigate this potential correlation further.

It should be mentioned that a graphical correlation analysis was chosen here instead of a mathematical one, since the most common Pearson's correlation coefficient is only valid for linear correlations (which is not given here), and other common correlation coefficients are also specifically used for certain mathematical correlations. As the recent analysis can only give a first idea of the mathematical form of the correlation, the mathematical analysis will be performed when more measurements have been taken and allow for plotting a more detailed graph from which a principle formula can be derived with high plausibility.

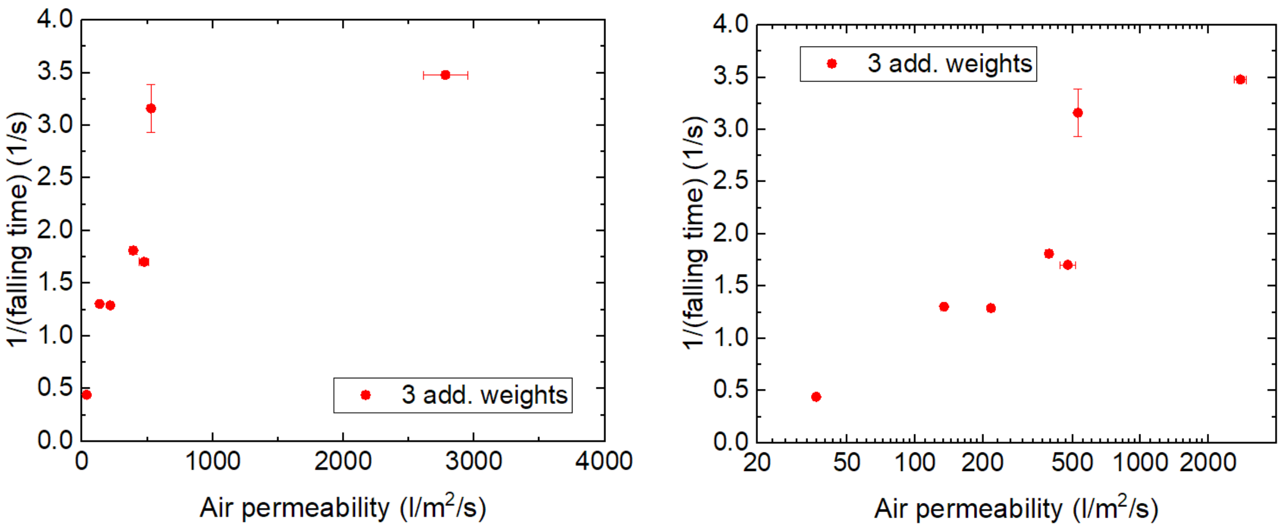

Fig. 3 Correlation of inverse falling time in both permeability testers, plotted against (a) a linear x-axis; (b) a logarithmic x-axis. The values are identical to those plotted in Fig. 2, with inverted y-axis.

These first correlation tests with an established standard show that the custom-made air permeability tester, based on the simple principle of a gravity-driven piston, may be a suitable alternative especially for schools and universities, which cannot afford buying a commercial test device working according to EN ISO 9237. Nevertheless, several potential problems regarding reproducibility have to be mentioned, which will be discussed below.

4 Discussion

Generally, the speed of the piston moving in the tube is increased by the normal force $F_N = mg$ with the piston mass *m* and the acceleration of gravity *g*. The pressure drop Δp, working on the cross-section of the piston A, results in a counteracting force $F_p = -\Delta pA$. Besides, a potential friction force, which cannot be excluded, works against the direction of movement, i.e. $-F_F$, which is not correlated with the piston mass, but with the pressure of the piston against the inner walls of the tube. In case of proper lubrication, the friction can be assumed to be very low, and to be negligible in a first approach.

In contrast, the pressure drop Δp can be estimated by the general gas equation, stating that pressure times volume stays constant in a closed system, i.e. $p(t)V(t) = p_0V_0$ with the starting values p_0 and V_0. It is clear that for an original volume V_0 = 0 ml, even a small increase of the volume $V(t)$ would require a pressure reduction to zero, i.e. a perfect vacuum, which is physically not possible. For a completely air-impermeable textile and otherwise perfect conditions (no air leakage around the piston), this would mean that the piston would not move at all. However, real experimental conditions cannot be expected to be perfect, and textile fabrics should allow for a certain air permeability, so that the piston will start moving.

It can be expected to accelerate until an equilibrium between F_N and F_p is reached, where F_p depends on the pressure drop between the pressure in the upper part of the tube and the outside, which again depends on the airflow through the textile, which reduces the pressure drop, and the speed of the falling piston, which increases the pressure drop. The recent test stand takes into account the necessity to reach this equilibrium to increase the reproducibility of the measurements.

Other potential reasons for reduced reproducibility, comparing custom-made test stands produced by different groups, are the potential leakage around the piston and the friction between piston and tube, which will depend on the combination of materials and the lubricant used. We thus suggest measuring the falling time of the piston in the tube without a textile fabric mounted on top and using this value to evaluate whether a test stand works properly. This procedure is similar to the evaluation of the plasticine viscosity in the test standard VPAM-KDIW, where the correct penetration depth of a defined stainless steel ball falling from a defined height onto the plasticine is defined [14].

Generally, after showing the basic correlation between established standards for air permeability measurements and the simple and inexpensive testing device suggested here, further experiments with more textile fabrics are necessary to evaluate this correlation in more depth. An interesting experiment that should also be performed is measuring the position-dependent piston speed by a high-speed camera. In this way, the distance until velocity becomes constant can be measured for different textile fabrics, additional weights and lubrication states, improving the reliability of the experiment by defining the optimum sensor positions based on these results.

5 Conclusions

To conclude, a gravity-based air permeability tester for textile fabrics was built and tested. A correlation between the inverse of the falling time of the piston in this experiment and the air permeability testing results according to EN ISO 9237 was found, while the recent test series was not yet sufficient to mathematically define a correlation function. In the future, more comparison measurements are necessary to establish a well-defined correlation, preferably in the form of an empirical formula. Besides, a high-speed camera should be used to fully understand the movement of the piston. Ideally, simulations of the airflow through the textile fabrics can complement the experimental results, thus paving the way to a new, inexpensive air permeability measurement technique.

Author Contributions

L. Sabantina: validation, formal analysis, investigation, writing – review and editing; A. Ehrmann: validation, formal analysis, writing – original draft preparation, visualization.

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Conflicts of Interest

The authors declare no conflict of interest.

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