

Design of a modern air permeability instrument comparable to Gurley-type instruments

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ABSTRACT: *Air permeability measurements by the Gurley method may take from several seconds to many hours to complete. Previously, the authors established the feasibility of using electronic pressure sensors and flow transducers to rapidly measure air permeability in the equivalent of Gurley seconds. Here, a new air permeability instrument is compared with the Gurley-type instrument. The measurement values are shown to be in agreement with those of the Gurley instrument. This technology can be used to test most grades of paper.*

KEYWORDS: *Air permeability, design, Gurley testers, instruments, paper tests, test methods.*

The main drawback with the Gurley-type instrument for the measurement of air permeability is the amount of time required for the test. In its current version, the instrument measures the time it takes for a certain volume of air to flow through the specimen as timed by marks on the side of the cylinder; the results are reported as Gurley seconds (1, 2). However, for tightly bonded or closed sheets, it may take much longer than just a few seconds to make the measurement—perhaps even several hours.

In a previous article (3), we reviewed the operational parameters of the

Gurley instrument and proved the feasibility of using electronic pressure sensors and flow transducers to rapidly measure air permeability in the equivalent of Gurley seconds. Drawbacks encountered in the prototype instrument were mainly with the air supply requirements because the mechanical-diaphragm air regulator used was unable to hold pressures within 1/100th of a kilopascal. This shortcoming is believed to have contributed to some of the 7% error encountered between the actual Gurley seconds and the converted values of measurements made with the flow transducers in the air resistance test range of 50–80

Gurley seconds. This error can be reduced to less than 5% with pressure adjustments made for each sample tested.

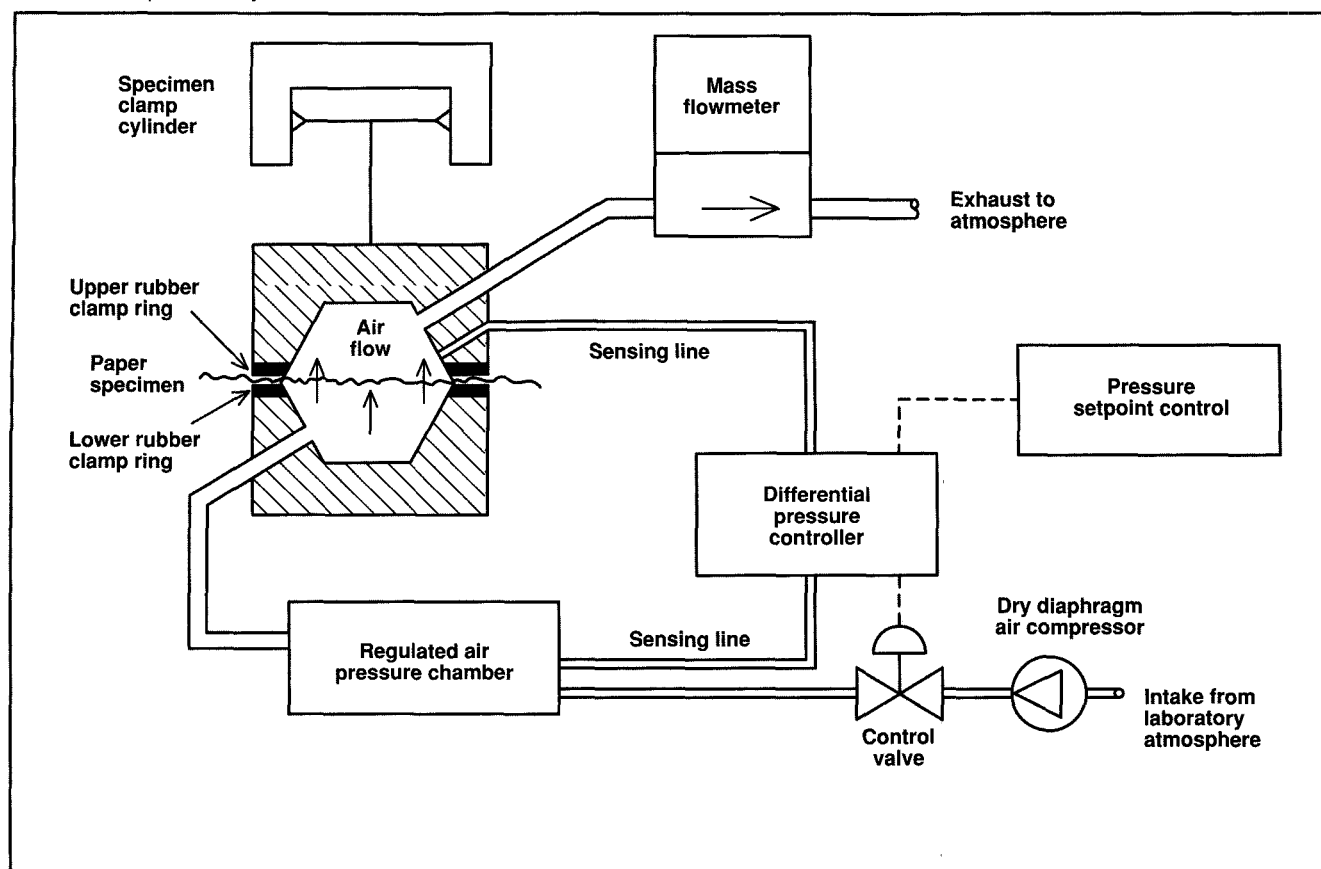
Another consideration in the error analysis is that “shop” compressed air was being passed through the sheet as part of the measurement system. This air would not necessarily be conditioned to the same 50% relative humidity as the air that is used in the normal instrument operated in a conditioned laboratory environment. Work with woven mercerized cotton broadcloth (4) indicated that air permeability is influenced significantly by the humidity of the air used in the test. For cotton cloth evaluated over the range of 0–95% RH, the scaled air resistance changed in a nonlinear fashion from 1.0 to 1.36. Because of the hygroscopic nature of cellulose, paper should likewise be sensitive to the humidity of the air used in the test.

Design of the air permeability test instrument

Figure 1 shows the design of the Hagerty Technologies Model 1 Air Permeability Tester. It uses a thermal mass flow sensor to measure the air flow that passes through the paper specimen. The specimen is clamped between an upper and lower rubber ring, loaded by means of an air pressure cylinder. The bottom rubber ring is self-aligning to the top ring to ensure a good seal under heavy loading conditions. The clamping rings have an inside diameter of 28.6 mm (1.125 in.).

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1. Model 1 air permeability tester



According to the manufacturer's specifications (5) for the W. & L. E. Gurley, Gurley-Hill S.P.S. Tester located at the University of Massachusetts—Lowell, with which the Model 1 is compared here, the Gurley instrument utilizes an exposure diameter of 1.128 in. This difference of 0.003 in. in diameter results in a loss of 0.5% of the area in going from the Gurley instrument to the Model 1 instrument. The software program in the Model 1 makes a correction using an area ratio factor to compensate for this difference.

A low-pressure source used for the measurement air is positioned within the testing environment. The purpose of this arrangement is to maintain a consistent relative humidity between the measurement air and the conditioning atmosphere, thus minimizing changes within the specimen. The air source for the measurement air is directed at the bottom side of the specimen.

The chamber above the specimen, sealed by the upper rubber ring, is

connected to the inlet of an electronic mass flowmeter. To maintain a constant pressure drop across the specimen, a differential pressure sensor measures the pressure drop across the specimen and in turn controls electro-pneumatic valves in the air flow network. This arrangement eliminates the problem of pressure loss in piping.

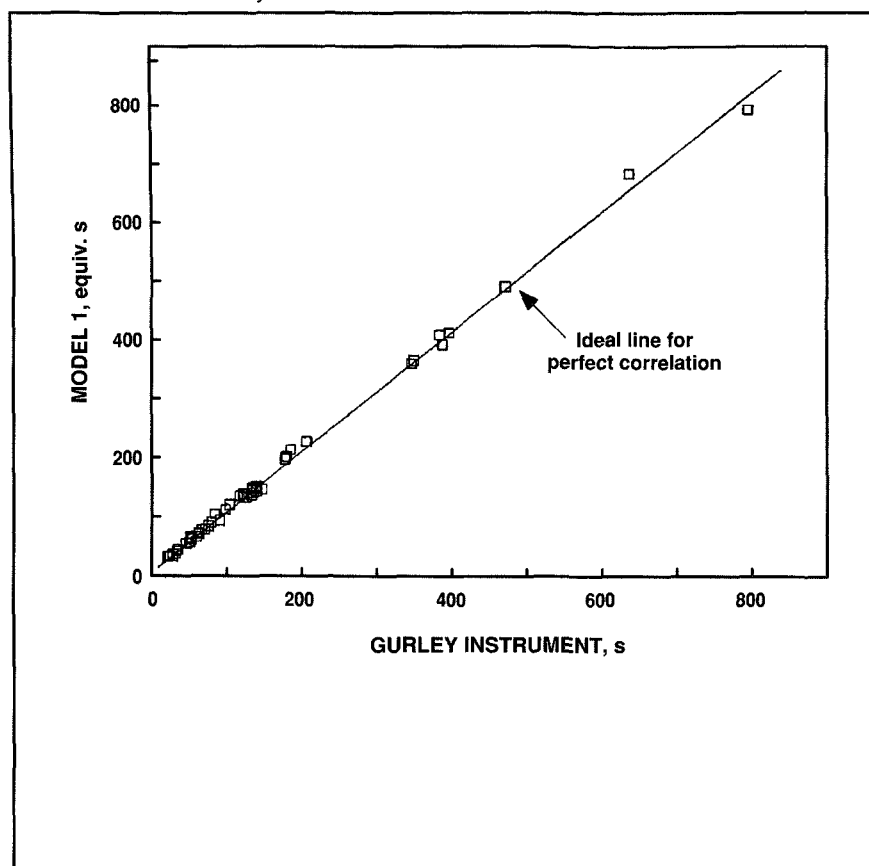
This configuration is not as sensitive to surface leakage to the atmosphere (resulting from specimen roughness) as the Gurley-type instrument. Surface leakage along the bottom rubber ring (the high-pressure side) is neglected because it is not included in the measurement. Surface leakage along the upper rubber ring (the low-pressure side) could affect the measurement. However, this leakage is thought to be very small because the pressure in the upper discharge chamber is close to atmospheric pressure; hence, the pressure differential across the seal is slight.

A microprocessor board with an analog to digital converter is used for data acquisition for the flowmeter and pressure signals and for control of the sequence of mechanical operations. The results are displayed digitally, with each test requiring about 6 s.

Test results

About 100 paper samples of various permeabilities were tested on both Lowell's Gurley instrument and the Model 1 air permeability tester with a test head pressure set at 1.22 kPa (4.90 in. H_2O at 60°F). In many cases, one single specimen was selected for evaluation on the Gurley-Hill S.P.S. instrument (because of long test times), whereas five specimens from each sample were tested and averaged for the Model 1 tester. The flow transducers were calibrated in milliliters per minute per square inch of test area at 1 atmosphere pressure and 23.1°C.

2. Results for the oil Gurley instrument vs. those for the Model 1 tester



Conversions were made for time, temperature, and pressure (1.22 kPa gauge) and for corrected actual volume of 107 mL of "free air" to yield equivalent Gurley seconds by the following conversion equation (3):

$$\text{Equiv. Gurley seconds} = \frac{60 \text{ s/min} (107 \text{ mL})}{\text{Flow (mL/min)}} \quad (1)$$

The results of this comparison are shown in Fig. 2, with the Model 1 results given in equivalent Gurley seconds as calculated using Eq. 1. The Model 1 air permeability instrument produced very good agreement in the range of 30–800 Gurley seconds of air permeabilities. Even though its flowmeter/data acquisition system was not designed to measure flows beyond 800 s, the correlation was still good up to 2500 Gurley seconds at 1.22 kPa.

Since many paper grades exhibit air resistance properties that fall outside of the working range of the flowmeter tested, we looked at other ways to ob-

tain measurements with the existing equipment. The practical solution to this problem is to increase the air flow through the test cell and specimen, so the measurements are made more in the center of the range of the flow transducer.

Historically, the most common approaches have been to increase the test area and to increase the test pressure. TAPPI T 536 om-88 describes a method that operates at 3.07 kPa (12.33 in. H₂O). TAPPI T 547 pm-88 describes a method that operates at 10.3 kPa (39.6 in. H₂O), with a selection of orifice diameters from 9.5 mm (3/8 in.) to 76.2 mm (3 in.). During the Lowell tests of the Model 1 air permeability tester, we decided to increase the air pressure drop across the paper specimen to 6.10 kPa (24.5 in. H₂O), exactly five times the pressure of the Gurley-type instrument and that of the first tests.

One would assume that the flows measured at the higher pressure would

be five times greater than those measured at the lower pressure, but that assumption does not account for the increase in air density, which allows more gas molecules to pass through the specimen. To correct for the air density changes by testing at the higher pressure, the Poiseuille–Hagen equation, which applies to ideal laminar flow through capillaries, can be used (6):

$$F = \pi a^4 M \bar{P} / [8 \eta R T L] \quad (2)$$

where

F = mass flow rate, g/s

a = radius of capillary, cm

M = gas molecular weight, g/mole

$\bar{P}$ = average of upstream and downstream pressure, dyne/cm²

ΔP = differential pressure across laminar flow element, dyne/cm²

R = gas constant (8.2×10^7 dyne·cm/(mole·K))

T = average temperature, K

L = length of capillary, cm

η = gas viscosity, g/(cm·s).

An examination of this equation reveals several terms that are associated with the porous media and will remain constant with changing pressure and terms such as air viscosity that will change little over a narrow range of pressures. Thus the ratio of the mass flow from one pressure to the next is primarily the ratio of the average pressure (absolute) times the differential pressure for each case. Using this analysis, the increase in mass flow resulting from the increase in pressure from 1.22 kPa to 6.10 kPa (gauge pressures) is calculated to be 5.12.

To confirm this analysis, Fig. 3 shows the results for flow through the same specimen at 1.22 kPa and at an elevated pressure of 6.10 kPa. A regression analysis of the data, when forced through zero, revealed a slope of 5.10 with a regression coefficient (r^2) of 0.999. This result would appear to prove the validity for the use of the

Paper Testing

Poiseuille-Hagen equation for the grades of paper tested for this study. Caution must be observed in applying the same approach to those grades of paper that have pinholes or relatively large passageways that do not restrict the air flow through the sheet to the laminar flow region.

Figure 4 shows this relationship in units of measurement that most people are familiar with, namely Gurley seconds, or seconds per 106 mL (corrected). The data analysis indicates that the inverse of the slope of the regression line is 5.31 (regression coefficient, $r^2 = 0.995$); the inverse is used to correct for the inverted relationship of Gurley seconds to air flow rate. This is an error of the 3.7% from the slope of 5.12 predicted from the Poiseuille-Hagen equation.

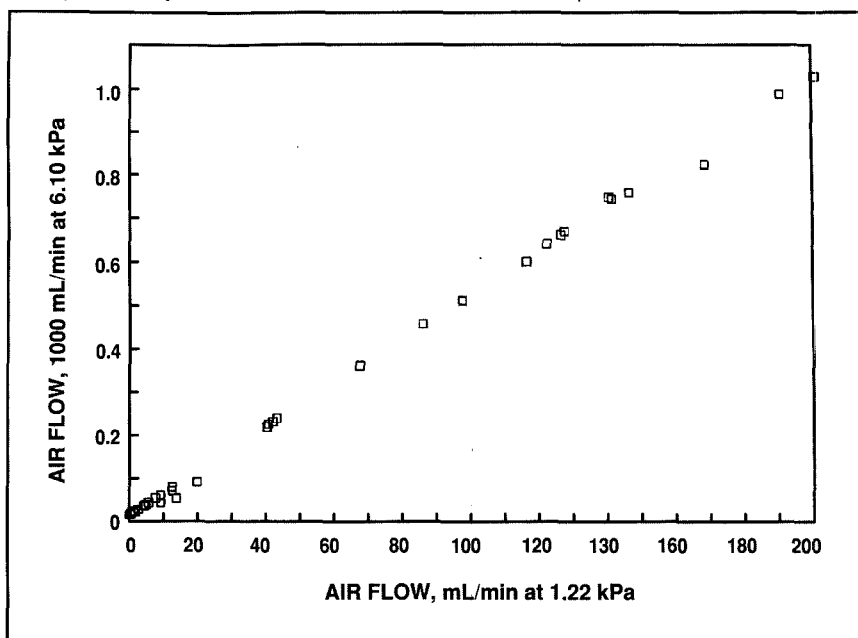
Conclusions

Instruments that use mass flow sensors can be used to measure air permeability at a much faster rate than possible with the Gurley-type liquid column devices, with the measurement values in substantial agreement with those of the Gurley instruments. To convert such measurements of flow rates into the more familiar units of "seconds per 100 mL," it is critical to measure and/or control the upstream and downstream pressures across the specimen.

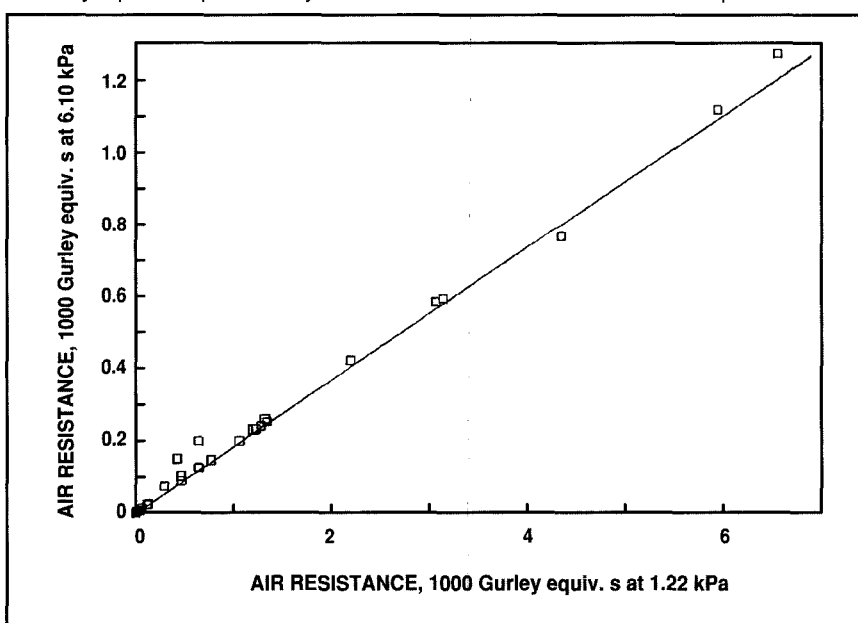
The Poiseuille-Hagen formulas seem to work well in converting the measured air flows back to the "Gurley seconds" as measured by the liquid column instruments in the ranges that we tested. By using mass flow sensors to measure the flow discharged from the specimen, personnel can significantly reduce the uncertainty of test results pertaining to errors caused by surface leakage across the specimen. The range of the instrument can be extended by performing the tests at elevated pressures and normalizing the test results back to what would be expected at the lower pressures.

With the proper selection of the flowmeter range, the test pressure set-

3. Air permeability measurements at normal and elevated air pressures



4. Gurley equivalent permeability measurements at normal and elevated air pressures



ting, and the clamping ring area, this technology can be used to test almost every grade of paper made today. 

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