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Measurement of Paper Porosity*

by D. Butters

Wiggins Teape Limited, London, England

1. BASIC DEFINITIONS

A definition for stipulating the way in which the passage of air through papers, used to wrap tobacco and filter rods, should be measured is proposed below. It is however first necessary to define the terms Air Permeability and Porosity.

Air Permeability is the measure of the facility of air flow as a property of a paper sample expressed in terms of rate of air flow, sample area and pressure responsible for flow. It can thus be defined independent of the instrument used, and is a true property. Under standard conditions and with laminar flow, the relationships are simple linear ones.

Porosity is used here as a general term indicating the property of a paper sample to allow the passage of air, this property being assessed in any of a number of possible ways.

2. THE IMPORTANCE OF PAPER POROSITY MEASUREMENT

The influence of air permeability of the cigarette tissue on cigarette smoke composition has been reported by many authors. As a few examples only, the papers of *Schur* and *Rickards* (1), *Lipp* and *van Nooy* (2), and *Terrell* and *Schmeltz* (3) show this influence.

It seems clear that the interest in, and need for, this type of investigation is very much on the increase. Interest in the effects of smoking on health will ensure that this continues.

As another example of the growing importance of air permeability measurement to the research worker we might consider the tremendous current interest in speciality ventilated cigarette tips. Here the need to define air permeability of the various unusual paper components is of paramount importance.

On a more common level, the effect of variations and changes in the porosity of filter plug wrapping paper can play havoc with the filter rod pressure drop or with the pressure drop control.

Thus it can easily be seen that this paper property is of considerable growing interest to the cigarette and filter rod manufacturer. Under such circumstances it must be of equal if not greater importance to the paper manufacturer.

We have seen the porosities of cigarette tissues move from their old levels of some 15 years ago to the use of papers with porosity levels 10 or 20 times higher.

3. SPECIAL REQUIREMENTS OF THE CIGARETTE TRADE

The cigarette trade makes certain requirements of a method of porosity measurement which are not common to all other paper users.

The shape and size of paper samples likely to be examined in the laboratory are certainly unique to the cigarette trade, ranging from cigarette spills of perhaps 70 mm × 25 mm, through long narrow bobbins to normal paper sheets. Any suitable air permeability or porosity tester must cope adequately and make the best use of all such samples.

Quality control and research laboratories place rather different demands on any instrument. The ideal control laboratory instrument is robust, built for rapid but trouble free operation when perhaps slightly misused by less skillful operators. In the research laboratory perfection and accuracy are the aim while time and operator skill and care, one hopes, are readily available. These differences are particulary significant in the paper manufacturing industry, but certainly exist (to a lesser extent) in many cigarette factories.

The precision of measurement required must of necessity vary from application to application. This is perhaps overshadowed by the intrinsic variability of this property of paper.

As has already been mentioned, the range of porosity levels of interest is expanding considerably, and it is of obvious value to refer all these porosities to the same scale and method of measurement — so far as is possible.

4. EXISTING METHODS OF MEASUREMENT

The number of types of instrument in common use, within the cigarette trade, is considerable. (If in addition one was to consider the various other pieces of equipment available to the general paper trade, all designed to give some indication of the way in which air will pass through paper, one would have a most complex situation.)

To further complicate the situation, there exists

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almost an equal number of definitions of the one basic property we wish to measure. As a simplification we find in practical use in various parts of the world:

A. Various Densometers measuring the time taken to displace a standard volume of air through a standard sample area under standard empirical conditions, e.g. standard methods of the British Paper Industry (4), backed by a British Standard (5), standard method of TAPPI (6) and of ASTM (7).
B. Instruments which measure the volume of air passing through a standard sample area in a standard time under the influence of a hydrostatic pressure which varies throughout the standard time, the extent of this variation being dependent on the permeability of the sample, or instruments which measure the time for a constant volume of air flow through the sample, under a continuously decreasing pressure difference.
C. Instruments which attempt to maintain the pressure drop across a standard area of sample while measuring the rate of air flow through the sample.
D. Instruments which measure the pressure drop across a standard sample area while passing air through at a standard flow rate and pressure.

Most instruments in use for cigarette tissues and filter rod wrapping papers fall within one of the three general categories A, B, or C and it is useful to examine these in the light of our known requirements. Densometer methods have proved to be quite acceptable standards for certain non-cigarette grades of paper — particularly when linked with automatic timing devices. Unfortunately the range of porosities which are of interest in our activities would require a number of standard instruments and cylinder sizes and a number of standard procedures — dependent on porosity level. We also find that a poor correlation is found between results using cylinders of different weights, suggesting that viscous and frictional forces play an important part. In addition it is rarely possible to reliably convert practical results back to absolute units of permeability, although generalised conversions can be done.
Methods in category B are widely used and perhaps the most popular. This however is hard to justify. The accuracy of the method falls off rapidly with increasing paper porosity since the significance of operator timing errors increases — in some cases — dramatically.
The word Greiner is used to describe a standard test in this category — but one very soon learns that there are a number of Greiner instruments, of different bulb size and specification, and thus giving different porosity measurements.
It is of course *theoretically* possible to convert low porosity readings on instruments of category B to absolute air permeability or to correct readings to a standard mean hydrostatic pressure, but for higher porosities this is doubtful.
Category C describes methods which perhaps offer the best practical solution of air permeability measurement. But in all cases, the physical design of the instruments with their inbuilt air resistance ensures that absolute results are not obtained.
The pressure drop methods of category D are used for the measurement of extremely high porosities as found for instance in oil filter papers.
It has already been suggested in 3. above that, regardless of the principle of measurement, the cigarette trade requires instruments for porosity measurement which are, robust yet sufficiently accurate and precise, able to cover a wide range of porosities and able to use a range of sample forms.

5. AIR PERMEABILITY OF CIGARETTE TISSUES AND PLUG WRAP PAPERS

Having considered all our requirements and all the measuring principles it was decided to use the standard definition of Air Permeability this being:
"The volume of air, at the standard temperature of 20° C, standard barometric pressure of 760 mm mercury and standard relative humidity of 65 % which passes through a paper sample area of 1 cm² in one second when drawn through the paper by a pressure difference of 1 gm per cm²".
This was then converted into a working definition:
"The rate of air flow through a 10 cm² area of paper sample when a pressure difference of 10 gms per cm² is maintained across the sample".
An instrument has been designed and built to use this working definition and meet the particular requirements of the cigarette trade.

6. THE AIR PERMEABILITY TESTER

In this instrument, air is drawn through the sample and a flow meter, by a vacuum pump; a needle valve in the line is adjusted to restrict the flow until 10 cm w. g. is developed across the sample. The pressure is read by a manometer tapped into the line near the clamp. There are two switches: one diverts the flow through one of three flow meter tubes to cover the full range and the other determines which clamp is to be used.
The vacuum system between the vacuum pump and the manometer is sealed by the paper sample in the clamp. Due to the fact that the paper sample is permeable, a measurable amount of air can be drawn through it and exhausted from the system by the vacuum pump. The rate at which the air is drawn through the sample, and thus its permeability, is indicated (in cc. min.) on the flow tube selected.
The pump and its associated needle valve control pressure of 10 cm. w. g. between the vacuum system and atmosphere, i. e. on both sides of the paper sample. This pressure difference is indicated on the manometer and maintained by the vacuum pump. The level of pressure is set by the needle valve.
The flow of air through the sample is indicated by the level of the float in the flow tube chosen by the selector switch. Three tubes are fitted to cover the ranges:

5 to 150 cc./min.
50 to 500 cc./min.
300 to 3000 cc./min.

The instrument possesses two clamps of 10 cm^2 and 2.5 cm^2 respectively. The 10 cm^2 clamp, which is fitted with strip guides, is designed to accept cigarette tissue as well as 10 cm × 10 cm samples. The 2.5 cm^2 clamp permits the checking of cigarette "spills" down to 20 mm in width. Small samples may be examined if placed under the clamp with care.

Sample Clamp

These have been carefully designed to hold the sample flat without lateral tension across the well (10 cm^2 in area) in the tester air system. A cigarette tissue bobbin may be mounted on the bench, and sample material from it fed through the strip guides on the clamp without interruption. If, however, ordinary 10 cm × 10 cm samples are to be tested, the strip guides may be simply dismantled by removing their retaining screws.

The instrument is operated on a firm, level surface in an atmosphere of 63 to 67 % R.H. and 65° to 71° F. There are no other installation requirements other than the provision of a 230 V.A.C. switched supply for the vacuum pump.

Calibration

A sealed port has been fitted into each of the measuring heads. The flows indicated by the rotameter tubes can be checked using a bubble tube or standard orifice by placing an impermeable sheet in the clamp, connecting the tube or orifice to the port and operating the vacuum system.

Accuracy

The rotameters are calibrated at 760 mm Hg and 20° C. It is possible to estimate the validity of this calibration with respect to the experimental conditions under which the rotameters are used.

The scale is being used at a pressure 10 cms water gauge below atmospheric pressure. In addition atmospheric pressure is rarely 760 mm Hg and, for instance, in the London area varies between 730 and 780 mm Hg.

The possible errors arising from these considerations must be considered in conjunction with a ± 3 % manufacturing tolerance on the rotameter tube calibration.

It is also necessary to account for the fact that the manometer does not measure the actual pressure drop across the sample but includes a factor due to back pressure within the instrument.

This work has indicated that when using the instrument under controlled conditions, the percentage of error in rotameter reading is likely to be between 3 and 5 %. We are, after all, looking for a practical instrument, and the accuracy has been found to be quite acceptable at porosities up to 1000.

7. CONCLUDING REMARKS

We have proposed that one universal and fundamental measure of air permeability replace the various porosity measures current in the trade.

We have developed a practical instrument to measure this property for cigarette tissue. While not being perfect, this instrument has been shown to give better measurement in practice than many of the other existing methods.

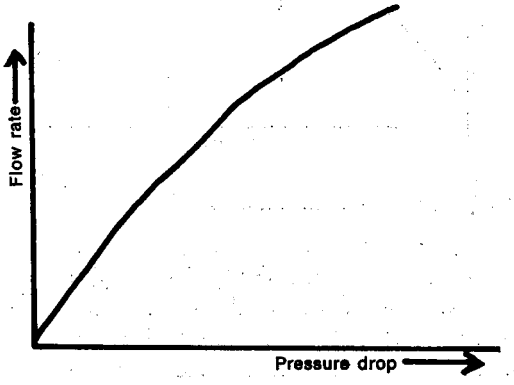
As paper porosity assumes greater importance and this world appears to get smaller as communications improve the need for agreed definitions and methods of measurement becomes more pronounced. It is hoped that this development can be regarded as a positive contribution to this end.

8. FUTURE WORK

A property which has for long been disregarded in relation to cigarette tissue, but which might be significant in the determination of the effects of paper on cigarette smoke, is Pore Size Distribution. We hope to carry out some work on this property in relation to cigarette tissue.

NOTES ON DISCUSSION

1. *Mr. Bond* (Cigarette Components) raised the question of "Edge Effects" in the sample clamp. He had found such effects on his instrument, and wondered if they had been found on the new instrument and, if so, were they not more significant on the 2.5 cm^2 head?
   Answer: Such effects had been eliminated in the sample clamp design mainly by careful selection of materials.
2. *Dr. Selke* (P. J. Schweitzer) criticised the definition of air permeability used, since he had found that, for papers exhibiting non-laminar air flow, the relationship between air flow rate and pressure drop across the sample was non linear as in the following diagram:



   Answer: It was agreed that the relationship between flow rate and pressure drop for turbulent conditions was as shown, while for laminar flow conditions, the relationship is linear. However, work so far had suggested that for most papers of naturally produced high porosity, the divergence from the linear relationship was not highly significant, particularly at the pressure drop level used. (See Additional Note.)
   Because, in the case of perforated papers, the air flow tends to become increasingly turbulent and the overall flow is probably partly laminar and partly turbulent, it was hoped that investigations into pore size distribution measurement might assist porosity measurement.
3. *Dr. Selke* considered that the instrument approximated

sensibly to actual smoking conditions, in that a cigarette is smoked at a given pressure drop which is not far removed from the 10 cms water gauge pressure drop specified for the instrument.

ADDITIONAL NOTES NOT GIVEN DURING DISCUSSION

1. *Dr. Butters*

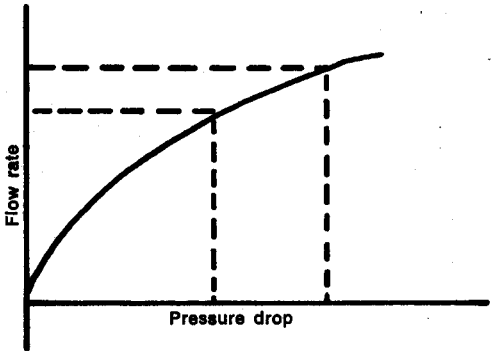
a) A cigarette being smoked at a given pressure (suction) rather than at a given flow rate, it makes sense to maintain a constant pressure drop in porosity measurement.

b) If air flow is *truly* laminar, flow rate is proportional to pressure drop and any error in the set variable causes a proportional error in the recorded variable.

but

c) For turbulent flow, flow rate levels off at increasing pressure drop and any variation in flow rate causes a disproportionately large variation in pressure drop. Pressures can be set to an accuracy of 1 % (i. e. 1 mm W.G. at 100 mm W.G.), while flow rates can be set to an accuracy of about 5 %.

Thus the experimental error is lowest if pressure drop, the more accurately adjustable variable, is kept constant.



2. *Dr. Lipp (Martin Brinkmann AG)*

In 1959 and 1960, an instrument for the measurement of the air permeability (porosity) of cigarette paper was developed by the laboratories of *Martin Brinkmann AG*, Bremen, which largely meets Dr. Butters' requirements. It has been described in detail in Beitr. Tabakforsch. 1 (1962) pp. 369–384. Since 1962 quite a number of the instruments have been delivered in more than 25 countries by the firm of Messrs. *Heinrich Borgwaldt* (2000 Hamburg 50, Friesenweg 4).

In comparison with Dr. Butters' instrument, our instrument has the advantage that surface contact is metal to metal and that there is no need for elastic materials such as rubber or plastic which would be deformed under pressure, resulting in a possible reduction of the area of measurement. Our measuring apparatus permits the simultaneous measurement of areas of paper of 20 or 40 cm^2, so that the resulting average is determined from a larger area of paper.

At the same time we were concerned with the definition of terms and units of measurement. The definitions we proposed in 1962 in the above-mentioned publication have largely been approved by the participants of the 5th Tobacco Colloquium (1963) who passed the resolutions which were published in Beitr. Tabakforsch. 2 (1964) pp. 151–156 and which are reprinted on the following pages of this issue.

A supplementary report on the measurement of perforated cigarette paper was published in 1966 in Beitr. Tabakforsch. 3 (1966) pp. 477–483.

The above-mentioned definitions and the said measuring instrument developed in our laboratory were included in the following Standard Methods:

a) *Verband der Cigarettenindustrie:*
Einheitliche Vorschriften für die Analyse von Tabak und Tabakrauch: Vorschrift 7, November 1963 (Beitr. Tabakforsch. 2–1964–pp. 157 and 158);

b) *CORESTA:*
Standard Method No. 10 published in September 1968 (see 8.1e);

c) *Deutsche Normen:*
DIN 10240 published in April 1969 (see 8.1.).

Definitions, apparatus and working method have been applied for more than ten years by the Cigarette Industry as well as by the Paper Industry and have proved to be most satisfactory. There is no need to set forth new definitions. The distinction between "standard definition" and "working definition" drawn by Dr. Butters is regarded as unsuitable and superfluous and must therefore be rejected.

SUMMARY

The "porosity" or "air permeability" of cigarette tissue is measured by many different instruments, is expressed in various units and it is frequently impossible to correlate such measurements and the readings of such instruments.

The property of a paper whereby it allows air and gases to pass through it while still containing the burning tobacco rod is of great and increasing interest in both the Research Laboratory and Raw Material Control Laboratory of the cigarette and filter rod manufacturer. Interest in papers of higher air permeability continues to grow, particularly in regard to the so-called "Health Hazards of Smoking", and thus the effect of smoke dilution.

Such interest by the cigarette and filter rod manufacturer necessarily means that the paper manufacturer must pay especial attention to this property during paper manufacture and in development work. He also requires to define and measure the property in his control and research laboratories.

Unfortunately, there is no common language to describe this property and as interest in higher porosities grows so the shortcomings of some methods of measurement are highlighted. The situation is further complica-

ted by the need of control laboratories for robust, simple to operate instruments, while a research laboratory might be more interested in accuracy and precision, while being less affected by the demands of careful operation and manipulation. Likely sample sizes can also vary, from small spills cut from individual cigarettes or rods, through long narrow skeins to the paper-makers' sheets.
A standard definition of air permeability of a sheet of paper has therefore been proposed and an instrument has been designed, using this definition, to meet the requirements of all interested parties. A number of these instruments have been built and proved by practical usage.

ZUSAMMENFASSUNG

Die „Porosität" oder „Luftdurchlässigkeit" von Cigarettenpapier wird mit einer Vielzahl verschiedener Geräte gemessen und durch verschiedene Maßeinheiten ausgedrückt. Oft ist es nicht möglich, Beziehungen zwischen den Meßverfahren und den Ergebnissen herzustellen.
Die Hersteller von Cigaretten und von Filtermaterialien interessieren sich sowohl in der Forschung als auch in der Qualitätskontrolle in starkem und zunehmendem Maße für die Eigenschaft von Papier, die es Luft und Gasen ermöglicht, das Papier zu durchdringen, während es den brennenden Tabakstrang umschließt. Das Interesse an Papieren mit stärkerer Luftdurchlässigkeit, die eine Verminderung der Rauchkonzentration bewirkt, nimmt vor allem im Rahmen der Diskussion über Rauchen und Gesundheitsschäden zu.
Dieses Interesse zwingt den Papierhersteller dazu, der genannten Eigenschaft im Herstellungsverfahren und in der Entwicklungsarbeit besondere Aufmerksamkeit zu widmen. Er muß diese Eigenschaft in seinen Laboratorien für Entwicklung und Qualitätskontrolle definieren und messen.
Unglücklicherweise wird diese Eigenschaft nicht einheitlich definiert und macht sich die Unzulänglichkeit mancher Meßmethoden zunehmend bemerkbar. Es kommt hinzu, daß ein Mangel an Laboratorien für Qualitätskontrolle besteht, die mit robusten und einfach funktionierenden Geräten arbeiten, während Forschungslaboratorien mehr Wert auf Exaktheit und Präzision legen. Außerdem unterscheiden sich die Probengrößen; sie reichen von kleinen geschnittenen Streifen, die von einzelnen Cigaretten oder Filterstäben stammen, über lange schmale Schnitzel bis zum Bogen des Papierherstellers.
In der vorliegenden Arbeit wird daher als Norm eine Definition der Luftdurchlässigkeit eines Papierbogens vorgeschlagen. Auf Grund dieser Definition wurde ein Gerät entwickelt, das den Bedürfnissen aller interessierten Gruppen entspricht. Eine Reihe von Geräten dieser Art wurde gebaut und in der Praxis geprüft.

RESUME

La «porosité» ou «perméabilité à l'air» des papiers à cigarette est mesurée par de nombreux appareils différents et exprimée en unités différentes, aussi est-il souvent impossible de comparer ces mesures et les valeurs indiquées par les différents appareils.
La propriété du papier qui lui permet de laisser passer l'air et les gaz alors qu'il contient du tabac en combustion est d'un intérêt toujours croissant tant pour les laboratoires de recherches que pour les laboratoires de contrôle des matières premières des fabricants de cigarettes et de filtres. L'intérêt pour les papiers à plus grande perméabilité à l'air continue à croître, surtout du point de vue des «implications pour la santé du fumeur», en raison de l'effet de la dilution de la fumée.

Un tel intérêt de la part des fabricants de cigarettes et de filtres signifie nécessairement que le fabricant de papier doit apporter une attention spéciale à cette propriété pendant la fabrication du papier aussi bien que pendant tout travail de perfectionnement; il est également nécessaire qu'il puisse donner une définition de cette qualité et la mesurer dans ses laboratoires de contrôle et de recherches.
Malheureusement il n'y a pas de termes consacrés pour décrire cette propriété et au fur et à mesure qu'augmente l'intérêt pour les porosités plus élevées, les imperfections de certains procédés de mesure sont mises en évidence.
La situation se complique en outre du fait de la nécessité pour les laboratoires de contrôle de disposer d'instruments robustes et de maniement simple alors que les laboratoires de recherches peuvent être plus intéressés par la précision et l'exactitude, même au prix d'une manipulation et d'un fonctionnement plus délicats. Les dimensions probables des échantillons peuvent aussi varier depuis de petits prélèvements sur une cigarette ou un bâtonnet-filtre jusqu'aux bandes longues et étroites, ou aux feuilles provenant de la machine à papier.
On a donc proposé une définition normalisée de la perméabilité à l'air d'une feuille de papier et conçu un instrument sur la base de cette définition afin de satisfaire les besoins de tous les intéressés. Cet instrument a été fabriqué en un certain nombre d'exemplaires et s'est avéré pratique à l'usage.
On présente la définition proposée pour la perméabilité à l'air, on décrit l'appareil et son mode d'emploi, et on discute de la nécessité d'une normalisation.

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The author's address:

Wiggins Teape Ltd., Gateway House,
1 Watling Street, London E.C. 4, England.