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OF EXTERIOR MEMBRANES AND SHEATHINGS

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A TEST METHOD TO DETERMINE AIR FLOW RESISTANCE OF EXTERIOR MEMBRANES AND SHEATHINGS

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ABSTRACT

This note describes a test method for determination of air flow resistance of exterior membranes and sheathings. The test specimen is placed between two chambers with different air pressures and the volumetric air flow rate through it at a steady state is determined. The relevant experimental quantities can presently be measured with precision better than 0.5% and with an accuracy of 2 to 3%, using commercial instruments. However, the instrumental precision does not mean much, due to the uncertainty introduced by material variability normally occurring in commercial products. This aspect of the test method is studied and a practical test procedure is suggested.

INTRODUCTION

The objective of this study was to develop test methods applicable to breather type membranes and exterior sheathing, for consideration by Canadian General Standards Board (CGSB). Moisture control committee of CGSB, responsible for this standard (CAN2-51.32-M77), decided that for adequate material characterization, in addition to the water vapour transmission test, air permeability and water penetration resistance tests should also be performed.

Since there are no ASTM test methods available for this purpose, Material Evaluation Department of Canada Mortgage and Housing Corporation requested that the Division of Building Research develop a new test method for determination of air flow resistance of exterior membranes. The CGSB Committee will review the proposed test method and recommend the criteria for material acceptance.

The relevant experimental quantities to be determined in the test method are a volumetric rate of air flow and a corresponding pressure difference. These two quantities can presently be measured with a precision better than 0.5% and with an accuracy of 2 to 3%, using commercial instruments. However this precision and accuracy will not mean much, due to the uncertainty introduced by material variability in commercial products. This aspect of the test method is studied and a practical test procedure is suggested.

THEORY

A unidirectional steady laminar flow of air through a porous membrane of thickness e, from a region of pressure p_1, to one of pressure p_2 is represented in Figure 1. From Darcy's law[1]

$$\frac{Q}{A} = -\frac{\kappa}{\eta} \cdot \frac{\Delta P}{e} \qquad (1)$$

where:

Q = volumetric flow rate of air,
A = normal cross-sectional area of the membrane,
κ = intrinsic air permeability of the membrane,
η = dynamic viscosity of air,
ΔP = difference in "piezometric pressure" of air across the membrane.

If the air pressure p_1 is not significantly larger than atmospheric pressure p_2 (and hence the difference $p_1 - p_2$ is not large) for all practical purposes

$$\Delta P \approx p_2 - p_1 \tag{2}$$

and equation (1) becomes

$$\frac{Q}{A} = \frac{\kappa}{\eta} \cdot \frac{\Delta p}{e} \tag{3}$$

where: $\Delta p = p_1 - p_2$.

Equation (3) is applicable to homogeneous materials and membranes. However, exterior membranes and sheathings are non-homogeneous. For practical application, therefore, it is useful to define the air flow resistance[2] (R) of the specimen as

$$R = \frac{\eta}{\kappa} \cdot e \tag{4}$$

From equations (3) and (4)

$$R = \frac{\Delta p \cdot A}{Q} \tag{5}$$

Thus from an experimental setup compatible with that shown in Figure 1, measurements of Q, Δp and A may be used to evaluate R. The air flow resistance determined will be an average property of the membrane for the metering area and so the membrane need not be homogeneous or of uniform thickness. The analogy between air flow resistance, as defined here, and apparent thermal resistance of a thermal insulation is obvious.

INSTRUMENTS

The experimental setup for the determination of air flow resistance is shown in Figure 2. The chambers A and B are made of plexiglas cylinders. The test specimen is placed between these chambers to separate them and held air tight with the help of an 'O' ring (Figure 3); further, the assembly is held together by a pressure jack. Compressed dry air from a regulating valve is admitted to the upper container. This air flows through the porous specimen into the lower compartment, which is open to the atmosphere. Consequently an appropriate steady state is maintained in the assembly. Different steady states can be achieved by changing the air pressure in the chamber A.

The steady state flow rate (Q) in equation (5) is measured by flow meters connected between the regulating valve and the upper chamber (Figure 2). Three different flow meters were used during the course of this study:

1) model 8141 manufactured by Matheson, with a measuring range of 0 to 5 $cm^3 \cdot min^{-1}$,
2) model 600 manufactured by Matheson, with a measuring range of 0 to 150 $cm^3 \cdot min^{-1}$,
3) model FM4333 manufactured by Union Carbide, with a measuring range of 20 to 900 $cm^3 \cdot min^{-1}$.

These flow meters were calibrated according to the soap bubble method commonly used in chromatography. A Hastings mini-flow calibrator (model HBM-1A) was used for this purpose. The accuracy of this equipment is estimated to be 0.25%.

Air pressure difference across the specimen was measured by using either

a) Validyne differential pressure transducer with model CDC 23 demodulator and a measuring range of 0 to 100 Pa, or
b) micromanometer MPGKDF manufactured by Air Instruments Resources Ltd. (Chalgrove, Oxford, UK), with measuring ranges of 0 to 0.5, 0 to 2, 0 to 5 and 0 to 6 kPa.

These instruments were checked by comparing with a "Dwyer Water Manometer" calibrated at the Division of Physics, NRC. The accuracy depended on the absolute value of the pressure. For example, from 20 to 500 Pa, the estimated inaccuracy fell from 6 to 2.4%. For the pressure range used in this test method, the accuracy of the instruments is within 2 to 4%.

The metering area A in equation (5) is defined by the 'O' ring. Under the clamping pressure of about 10 kPa, compression of the O-ring reduces the metering area to 143.6 cm^2. Thus $A = 143.6 \pm 0.3$ cm^2 has been used.

According to equation (3) one measurement under steady state condition is sufficient to determine the ratio ($\Delta p/Q$). However this ratio could be more precisely determined by measuring Δp as a function of Q and by a subsequent least-squares analysis.

PRECISION OF THE TEST METHOD

The precision of the test method was estimated by studying the air flow resistance of grade 1 and grade 4 quantitative filter papers, as follows. One specimen of grade 1 filter paper was used first to check the precision with which Q and Δp are measurable. Eight flow rates from 3.34 to 150.3 $m^3 \cdot s^{-1}$ were chosen arbitrarily. These flows were reproducible with a precision better than 0.25%. In a series of measurements these flows were reproduced five times and each time the corresponding pressure differences were measured. The average deviation of these pressure measurements was 0.05 Pa and the pressure differences measured were between 0.9 and 26.3 Pa. The average precision attainable in this range is thus better than 0.5%.

Four other series of measurements were done under the assumption that these filter papers are ideally homogeneous materials. In the second series, five different grade 1 papers were used and in the third series, five different grade 4 papers. In the fourth series, five grade 1 papers were stacked together in five different orders and each resultant stack was studied as a separate membrane. The fifth series was a repetition of series three with five grade 4 papers put together. The results are summarized in Table 1 and the linear dependence of Δp on Q is shown in Figures 4 and 5. Results of the linear least-squares analyses are given in Table 2. The values of the intercept and the slope were found for each series of measurements. In principle, the intercept should always be equal to zero. In practice, the residual values for the intercept, shown in Table 2, are a measure of experimental imprecision. The influence of this imprecision on the calculated R-value for flow rates higher than 20 $cm^3 \cdot min^{-1}$ is negligible. The slope ($\Delta p/Q$) in equation (5) is determined in each case with a standard error $<1.1\%$ and this is a measure of the overall precision attainable from this test method.

PILOT STUDY ON SELECTED COMMERCIAL PRODUCTS

The precision quoted above is valid for ideal materials with uniform pore size and distribution, like the filter papers used in the series. For real materials this ideal situation is seldom realized. Hence, the following pilot study was undertaken to formulate a test procedure for commercial products. Ten rolls of breather membranes or papers were selected from products delivered by various Canadian manufacturers. Specimens were taken from random locations on each roll and each specimen was designated with a roll number and a specimen number. The different samples chosen included membranes such as asphalt-saturated felt (both plain and perforated), saturated building paper and breather type sheathing and plastic membranes.

From each roll four specimens were studied. The results are summarized in Table 3, along with an appropriate statistical analysis. The test method when applied to nearly ideal membranes like filter papers allows a determination of air flow resistance with a variation of 2 to 4%. At the same time, as seen from Table 3, similar tests on commercial membranes can result in a variation of 50 to 100%. This large variation is attributable to material inhomogeneity. However it may be important to look at this variability in terms of the size of the metering area and the number of specimens tested.

The size of the metering area indeed influences the air flow resistance, as is demonstrated from the following measurements with a Gurley densometer on membranes 7 and 10. The densometer measures the time taken by 100 cm^3 of air at a pressure of 1.2 kPa to flow through a 5 cm^2 area of the membrane. Various measurements on membrane 10 recorded times between 26 and 75 s and on membrane 7, between 8 and 306 s. Thus 5 cm^2 is far too small a metering area for materials with large spatial variability. The area chosen for the test method described here is approximately 30 times larger than the metering area in the densometer; it will reduce the variability of the results considerably. This metering area is also five times larger than the minimum required in the similar test for water vapour transmission, described by ASTM Standard test method E96-80.[3]

Since material non-uniformity introduces large variability in the test results, one way to overcome this is to increase the number of specimens studied. However, for practical and economic reasons this number will have to be kept relatively small. Results obtained by studying five specimens from each sample may reduce the variability to an acceptable level.

APPLICATION OF THE TEST METHOD

The test method described above was used to determine air flow resistances of fifteen different membranes; these included the ten samples used for the pilot study and five additional samples.

The following test procedure was specified:

1) five specimens to be tested and the average of five results reported as air flow resistance of the material;
2) at least four data pairs to be used to calculate the air flow resistance;
3) as appropriate for any specimen, pressure differences ranging between 1 and 1200 Pa and air flow rates ranging between 20 and 900 $cm^3 \cdot min^{-1}$ to be used.

The results of these studies are summarized in Table 4. By increasing the number of specimens from four in the pilot studies to five, the width of a confidence interval calculated on a 95% probability level is significantly reduced (e.g. from 97% to 57%). The uncertainties are still relatively high, but the average values of the airflow resistances listed in Table 4 are acceptable for material characterization and practical calculations.

The test method for determination of air flow resistance may be applied to membranes or to sheathing materials. In the latter case two additional requirements should be specified: (1) maximum thickness of the specimen, and (2) sealing of the edges. Specimen thickness will be limited to 32 mm, similar to the requirements of the ASTM E96-80 standard.[3] The seal of paraffin wax on the specimen edges may also be used (see Figure 6). A simpler procedure, applicable for homogeneous materials with low air flow resistance, consists of testing larger specimens so that the metering area is enclosed by a collar 3 to 5 cm wide, which provides sufficient resistance to the lateral flow of air.

In summary, the proposed test method was suitable for testing both membranes and boards. The objectives formulated for this project have been achieved by the development of the test method. Collecting data on different materials is beyond the scope of the test method development. However, in engineering applications a new test method may only be accepted when its applicability is proven with respect to materials of known performance. To generate some comparative data, a few air barriers and exterior sheathing materials were tested. The results are summarized in Table 5.

REFERENCES

1. Dullien, F.A.L. Porous Media - Fluid Transport and Pore Structure, Academic Press, New York, p. 79, 1979.

2. Standard Test Method for Airflow Resistance of Acoustical Materials, Annual Book of ASTM Standards Part 18, ASTM C522, p. 262-267, 1981.

3. Standard Test Method for Water Vapor Transmission of Materials, Annual Book of ASTM Standards, Part 19, ASTM E96-80, p. 1002-1011, 1981.

Table 1. Volumetric flow rate of air (Q) and pressure difference (Δp), filter test series 1 to 4. Numbers in parentheses are standard deviations of five independent measurements.

$Q \cdot 10^7$	Δp(Pa)							
$m^3 \cdot s^{-1}$	Series 1		Series 2		Series 3		Series 4	
3.34	0.9	(0.1)	0.5	(0.0)	3.0	(0.0)	1.1	(0.1)
10.02	1.9	(0.1)	1.0	(0.0)	8.3	(0.1)	2.9	(0.1)
26.72	4.4	(0.1)	1.7	(0.0)	20.3	(0.4)	6.9	(0.1)
46.76	8.2	(0.1)	2.9	(0.1)	36.7	(0.3)	12.2	(0.2)
66.80	11.4	(0.2)	3.9	(0.2)	51.2	(0.4)	17.0	(0.2)
93.52	16.4	(0.2)	5.5	(0.4)	74.0	(0.6)	24.5	(0.1)
120.24	20.8	(0.2)	7.1	(0.4)	93.6	(1.0)	31.0	(0.1)
150.30	26.3	(0.2)	8.8	(0.4)	117.5	(0.6)	38.8	(0.1)

Table 2. Summary of linear least-squares analyses and mean air flow resistance (R); numbers in parenthesis are standard errors.

Series No.	Intercept Pa	$\frac{\Delta p}{Q} \cdot 10^7$ $Pa \cdot s \cdot m^{-3}$	Standard deviation Pa	Linear correlation coefficient	$R \cdot 10^{-4}$ $Pa \cdot s \cdot m^{-1}$
1	0.06 (0.12)	0.173 (0.002)	0.2	0.9998	2.44(0.03)
2	0.28 (0.06)	0.0563 (0.0007)	0.1	0.9995	0.80(0.06)
3	0.08 (0.39)	0.780 (0.008)	0.7	0.9999	11.20(0.06)
4	0.18 (0.12)	0.257 (0.002)	0.2	0.9999	3.68(0.00)

Table 3. Air flow resistance (R) of commercial membranes, as determined during pilot study. Confidence interval refers to 95% probability level.

Roll No.	$R \cdot 10^{-4}$ $Pa \cdot s \cdot m^{-1}$					Confidence interval	
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Average	$\pm\Delta R$ $Pa \cdot s \cdot m^{-1}$	percent
1	413.9	355.8	332.4	350.6	363.4	42	11
2	10.53	4.57	6.01	11.88	7.84	10	50
3	38.9	40.6	34.8	31.9	36.2	5	13
4	16.7	15.3	16.2	16.3	15.7	1	4
5	079.0	250.6	387.6	227.0	485.8	482	97
6	66.1	112.4	82.9	67.7	82.3	26	31
7	577.1	632.0	787.7	431.6	607.3	176	29
8	173.1	153.7	143.2	146.7	153.8	16	10
9	138.6	144.6	186.3	181.5	162.6	30	18
10	5.74	5.42	6.31	5.92	5.88	0.4	7

Table 4. Air flow resistance (R) of membranes. Confidence interval refers to a 95% probability level.

Membrane No.	$R \cdot 10^{-4}$ $Pa \cdot s \cdot m^{-1}$ Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Mean value	Confidence interval percent
1	284.3	289.0	370.3	354.6	445.5	348.7	18
2	5.96	9.16	7.74	4.92	4.22	6.86	30
3	40.12	36.0	35.7	37.1	33.5	36.2	6
4	17.0	16.8	16.8	25.1	15.2	18.6	20
5	245.6	341.4	265.0	282.2	254.9	278.2	13
6	34.4	133.5	55.4	37.9	81.9	68.6	57
7	731.4	555.6	473.3	630.1	389.8	556.4	23
8	194.5	205.1	165.9	165.0	176.1	181.2	9
9	159.7	179.8	174.3	212.3	216.2	188.1	12
10	5.51	6.51	6.01	6.45	4.83	5.88	11
11	136.0	184.1	151.8	155.1	279.9	181.2	30
12	40.8	28.0	14.6	27.0	22.8	26.4	34
13	257.9	242.1	198.6	266.2	182.1	229.2	15
14	1.61	1.03	1.90	3.36	2.56	2.06	41
15	86.4	80.3	71.9	90.5	89.3	83.3	9

Table 5. Air flow resistance of selected air barriers and exterior sheathing materials.

Material	Average R $Pa \cdot s \cdot m^{-1}$	Range $Pa \cdot s \cdot m^{-1}$
0.15 mm (6 mil) polyethylene	no measurable air flow	-
0.05 mm (2 mil) polyethylene	no measurable air flow	-
0.15 mm (6 mil) polyethylene with one pinhole (0.8 mm)	$4.4 \cdot 10^7$	$2.5\text{-}7.8 \cdot 10^7$
25 mm thick polystyrene	$1.6 \cdot 10^4$	$0.8\text{-}2.8 \cdot 10^4$
12 mm thick insulating fibreboard sheathing	$4.6 \cdot 10^4$	$3.6\text{-}5.3 \cdot 10^4$

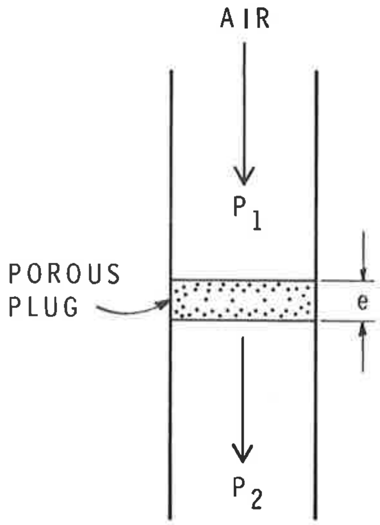
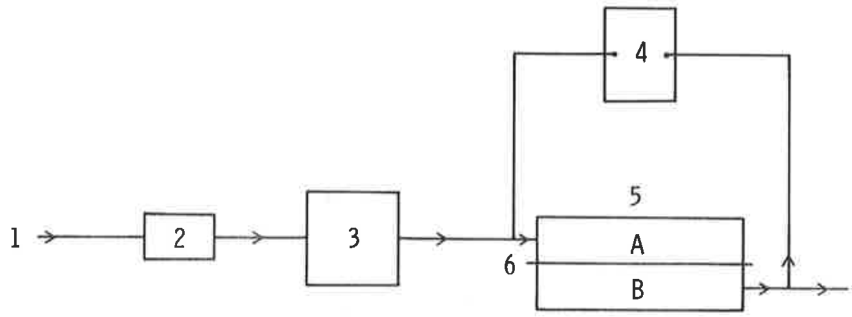


FIGURE 1

UNIDIRECTIONAL LAMINAR FLOW OF AIR THROUGH A POROUS MEMBRANE

BR 6655-1



1 COMPRESSED AIR
2 REGULATOR
3 FLOW METER
4 MANOMETER
5 TEST CHAMBERS A AND B
6 MEMBRANE UNDER TEST

FIGURE 2

EXPERIMENTAL SET-UP FOR DETERMINATION OF AIR FLOW RESISTANCE

BR 6655-2

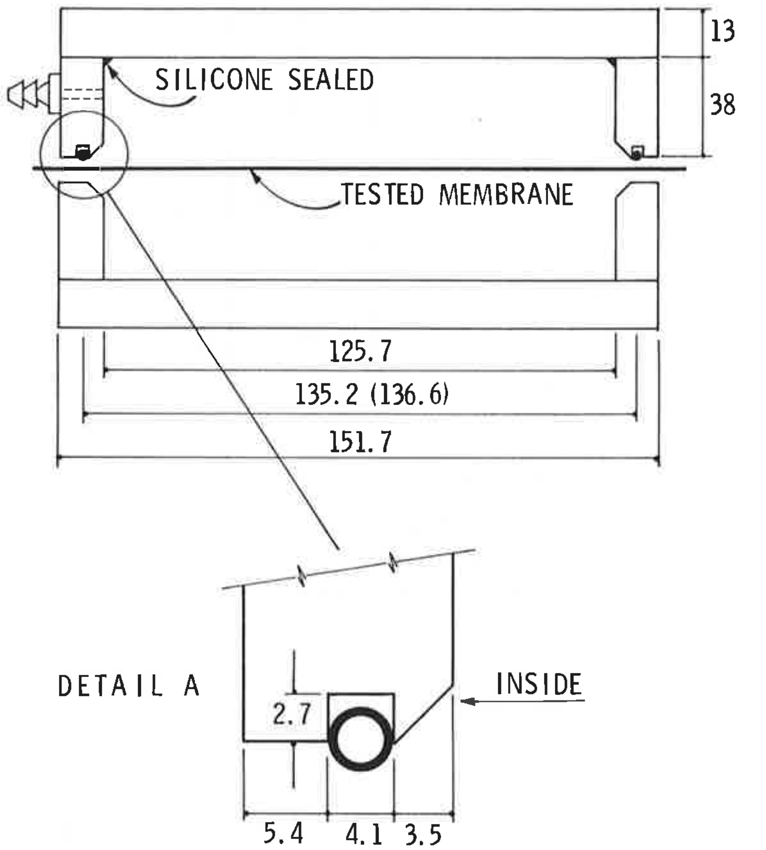


FIGURE 3

TEST CHAMBER WITH A MEMBRANE UNDER TEST. CLAMPS WITH PRESSURE 10 kPa COMPRESS O-RING 0.3 mm, CHANGING THE DIAMETER OF THE SPECIMEN FROM 136.6 TO 135.2 mm. METERING AREA OF 143.6 ±0.3 cm^2 IS USED FOR CALCULATIONS

BR 6655-3

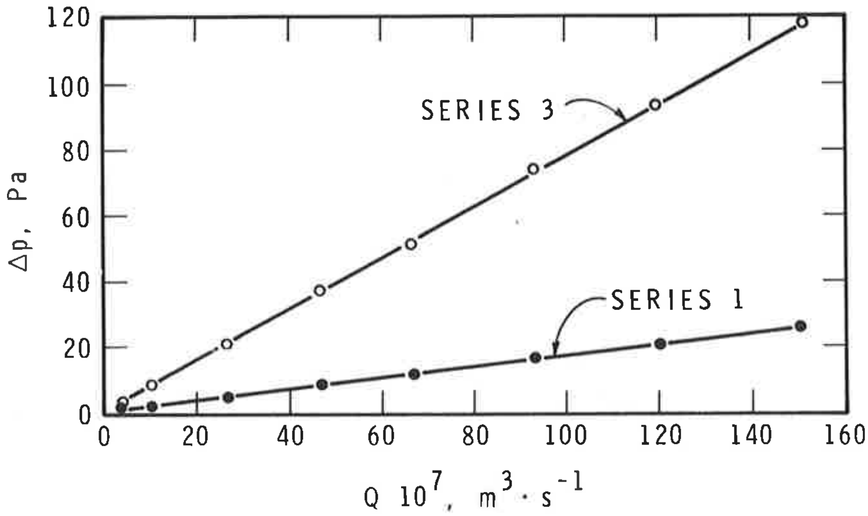


FIGURE 4

LINEAR DEPENDENCE OF PRESSURE DIFFERENCE Δp ON RATE Q OF AIR FLOW FOR PRECISION TESTS ON FILTER PAPER

BR 6655-4

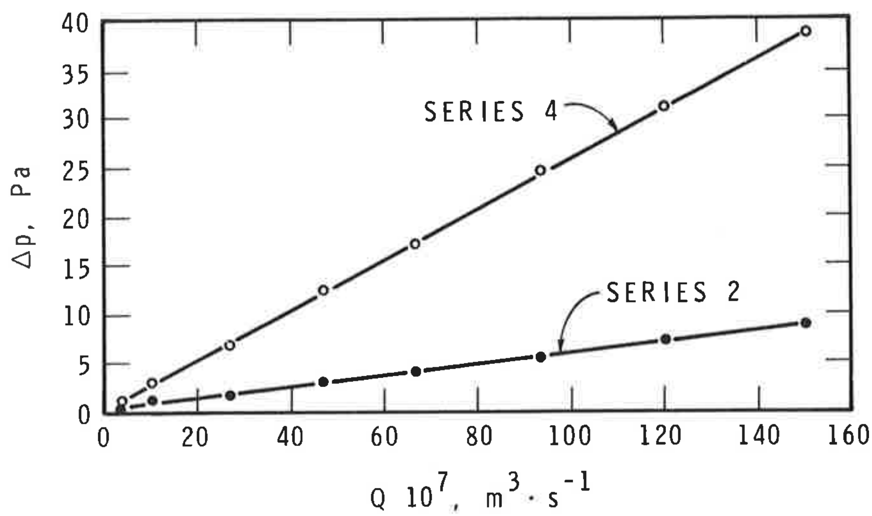


FIGURE 5

LINEAR DEPENDENCE OF PRESSURE DIFFERENCE Δp ON RATE Q OF AIR FLOW FOR PRECISION TESTS ON FILTER PAPER

BR 6655-5

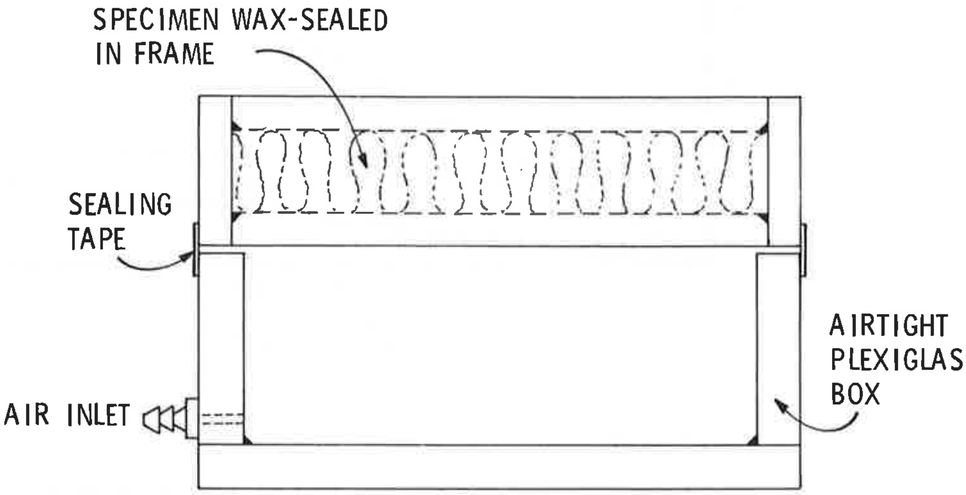


FIGURE 6

PLEXIGLAS TEST CHAMBER (300 x 300 x 75 mm) FOR TESTING THICK SPECIMENS

BR 6655-6