AN APPARATUS FOR DETERMINING WATER VAPOUR PERMEABILITY OF FABRICS

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ABSTRACT

An apparatus for the determination of water vapour permeability (W.V.P.) of fabrics is described. The fabric partitions a closed space into two compartments in which are circulated air streams having high and low water vapour pressures respectively, without any overall pressure or temperature difference. The transfer of moisture from the high to the low humidity side of the fabric is gravimetrically measured. Results of tests are given.

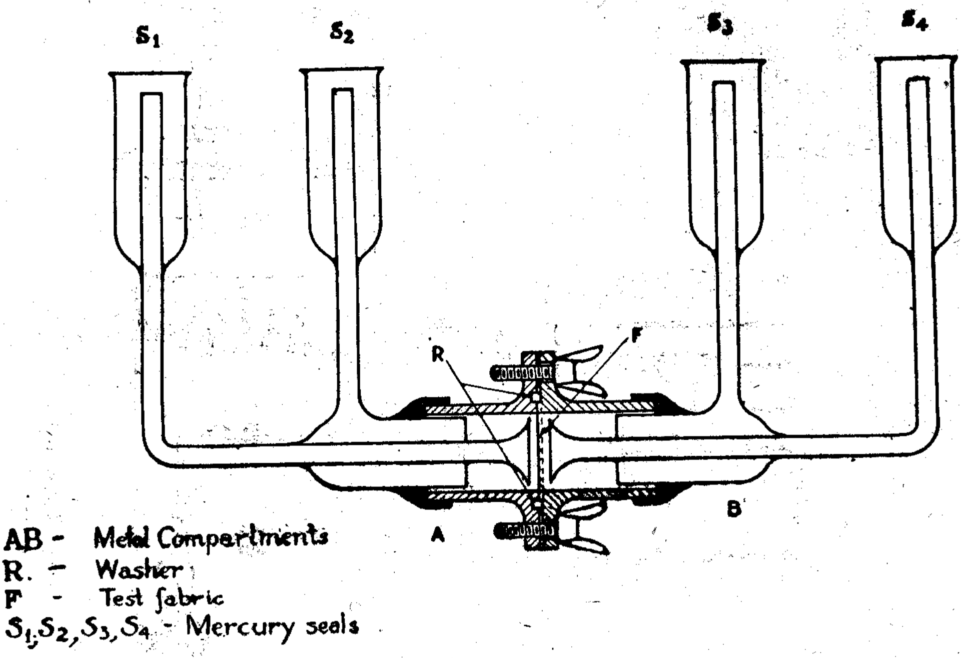
Under tropical conditions the ambient temperature is either equal to or higher than that of human body, in consequence of which the elimination of metabolic heat can only occur by sweat evaporation. The clothing, therefore, should have adequate water vapour permeability (W.V.P.) to help this process. A routine testing method for evaluation of W.V.P. was devised and is described in this paper.

Peirce, Rees and Ogden[1] have used a porous pot filled with water and covered with a cellulose acetate membrane through which only water vapour can permeate and found the resistance to water vapour transmission (which is the reciprocal of W.V.P.) from the loss of water in the pot. This membrane is next covered completely with the test fabric and the resistance to water vapour transmission of the combination is found out. The difference between the two results enables the resistance of the fabric to be calculated.

Goodings, Kitching & Tucker[2] determined the W.V.P. by the loss of water from aluminium cells partly filled with water and covered with the test fabric. A stagnant air gap was produced by a shield fabric having high W.V.P. but low air permeability fixed parallel to the test fabric at a short distance above. The method, however, was not very sensitive.

In both the methods described above, static conditions prevail. A method in which dynamic conditions exist and in which any desired relative humidity can be maintained on the two sides of the fabric has been devised, similar to those adopted for varnish films by (*i*) Thomas & Gent[3] and (*ii*) Blackman & Davies[4]. By providing for moving air on either side of the fabric under test, such a method simulates better the conditions under which fabrics are used in practice.

The permeability cell is illustrated in Fig. I. The fabric F is held flat without any crease between two flanged metal compartments A & B provided with a rubber washer R and clamped together by means of winged screws. No tension except that due to its own weight is applied to the fabric.



AB - Metal Compartments
R. - Washer
F - Test fabric
S_1, S_2, S_3, S_4 - Mercury seals

Fig 1

The general lay-out of the apparatus is shown in Fig. 2. Moist air from the humidifier D_1 is led into copper coil L_1 and then to the aqueous bubbler W where it is saturated with water vapour at the bath temperature. The moist air finally enters the compartment A through mercury seal S_1. After circulating over the fabric, the air stream leaves the compartment through mercury seal S^2 and passes out via capillary flow meter M_1. The moist air flow is regulated by the stopcocks C_1 and C_2.

Dry air from the dehumidifier D_2 is similarly led through a copper coil L_2 in order to attain the bath temperature to compartment B through mercury seal S_3. It leaves the compartment through mercury seal S_4 and passes out *via* capillary flow meter M_2 and the stopcocks C_3 and C_4 regulating the flow. The two U-tubes T, T packed with a mixture of silica gel and phosphorus pentoxide are used to absorb the moisture carried over by the stream of dry air.

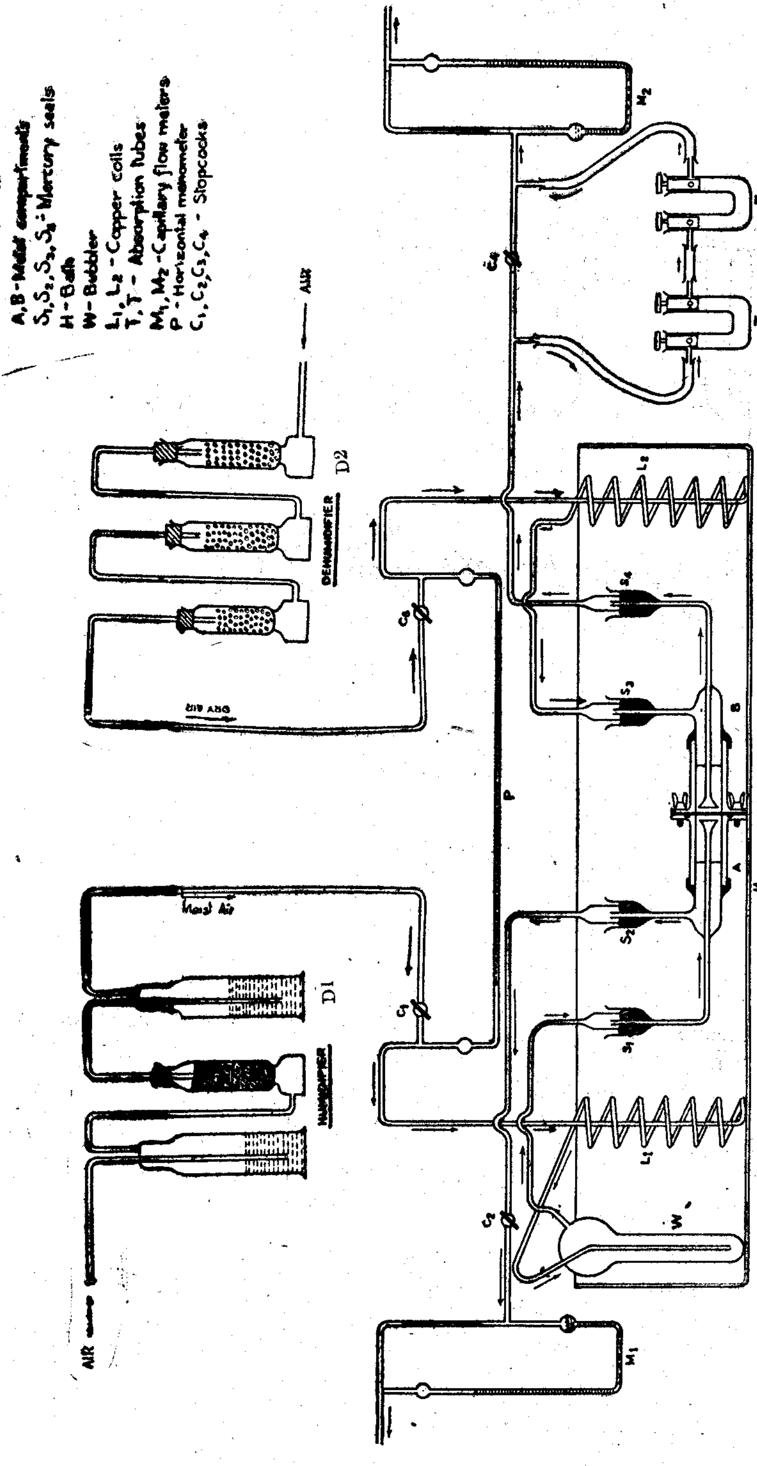


Fig 2—General Lay-out

The permeability cell, the copper coils L_1 and L_2 and the bubbler W are kept immersed in a thermostatic bath H which can be maintained at any desired temperature with an accuracy of ± 1°C with a toluene mercury thermo-regulator. All determinations were carried out at $30° \pm 1°$C which is in the neighbourhood of generally accepted average normal skin temperature.

It will be seen that moist air enters by the central tube and leaves by the side tube whereas the dry air enters by the side tube and leaves by the central tube. This arrangement, which is similar to that reported by Blackman & Davies[4], was adopted since it gave more consistent values than the reverse arrangement originally used. The rates of flow of the moist and the dry air as measured by flow meters M_1 and M_2 are kept equal and constant during any single determination. To indicate equality of pressure on the two sides, a horizontal manometer P is connected across the two compartments of the permeability cell.

Air with the required moisture content is circulated through the two compartments of the permeability cell for a considerable length of time depending upon the type of fabric (varying from ½ an hour to 2 hours) in order that the fabric attains an equilibrium moisture gradient. That this equilibrium has been reached can be seen from two consecutive determinations giving concordant values for water vapour permeability of a fabric. To make a determination, the stopcock C_4 is closed and the outgoing stream of dry air is diverted through the weighed absorption tubes T, T and the increase in weight over a known period of time is noted. The W.V.P. of the fabric defined as the gms of water vapour permeating per sq. meter of the fabric per hour per millimeter of mercury difference in vapour pressure, is then calculated from the formula—

$$\text{W.V.P.} = \frac{m \times 100^2}{A \times P}$$

where m is the mass in gm. of moisture diffusing through the fabric in one hour.

A is the area of the fabric in square centimeters.

P is the vapour pressure difference between the two sides in millimeters of mercury.

The vapour pressure difference between the two sides of the fabric is taken as the actual vapour tension corresponding to the R.H. of the moist air at the temperature of the bath since on account of the usually employed high rate of flow of air, the pressure on the dry air side due to the diffusing vapour will be negligibly small. The R.H. of the moist air is determined experimentally.

Reproducible values can be obtained by this method provided care is taken to regulate the flow and the pressure of air on both sides of the fabric. Water vapour permeability figures obtained under such conditions for the same piece of fabric in three repeat tests are given in Table I and show a variation of less than ±2% from the mean value.

TABLE I

Serial No.	Sample	Threads per inch		Count		Thickness in 1/1000 inch under 0·1 lb. per sq. inch.	Weight per sq. yard. (oz.)	Water vapour permeability gms./sq. m/hr/mm of Hg.
		Warp	Weft	Warp	Weft			
1	Close weave cotton fabric 5 oz. (dyed olive green).	184	90	2/80	2/80	10	4·8	16·85 17·04 17·02
2	Cellular cotton fabric (dyed olive green and treated with oxalic acid).	71	51	24^{s}	14^{s}	27	5·2	18·71 18·43 18·31
3	Oxford weave cotton fabric (dyed olive green).	162	71	32^{s}	25^{s}	19	5·9	17·34 17·18 17·74

W.V.P. figures obtained for some typical fabrics by this method are given in Table II. The value against each fabric is the average of a number of values obtained with different portions of the same fabric. The difference in thickness of the cellular cotton fabric reported at Serial No. 2 of Table I and Serial No. 5 of Table II is due to the fact that the former was given an oxalic acid treatment which has produced an increased thickness, and is accompanied by a decreased W.V.P.

TABLE II

Serial No.	Sample	Threads per inch		Count		Thickness in 1/1000 inch under 0·1 lb./sq. inch	Weight per square yard. (oz.)	Water vapour permeability gms/sq. m/hr/mm of Hg.
		Warp	Weft	Warp	Weft			
1	Thrown silk fabric	332	120	50 (Deniers)	47	9	3·0	21·5
2	Spun silk fabric	321	194	42 (Deniers)	46	10	3·2	19·9
3	Oxford weave cotton fabric.	138	60	32^{s}	26^{s}	14	5·0	20·9
4	Plain weave cotton fabric.	108	45	21^{s}	18^{s}	17	5·7	22·5
5	Cellular weave cotton fabric.	71	51	24^{s}	14^{s}	20	5·2	22·0

No special attempt was made to study the effect of relative orientation of the different layers of a composite fabric. The results of a number of repeat tests in which no special adjustment of orientation of different layers was made, were sufficiently close to one another to justify their average values as given in Table III to be obtained. This fact may be taken as indirect evidence to show that relative orientation of the different layers of a multiple fabric does not apparently make any marked difference to the W.V.P. The results of tests on multiple layers of the same fabric (Table III) show that the resistance to water vapour transmission does not bear a linear relationship with fabric thickness as reported by some workers[1,2]. The variation of W.V.P. with thickness apparently involves some complicated relationship indicating that the process is not one of simple diffusion through the fabric pores but may involve some contribution by the fibres of the fabric also. This aspect is worth further study.

TABLE III

Number of layers of closely woven fabric 5 oz. (item 1 of Table I).	Water vapour permeability gms/sq. m/hr/mm of Hg.
Single	16·97
Double	14·05
Triple	11·88

The work described above has been carried out as part of the development programme on physiological evaluation of clothing and this paper is published by the kind permission of the Director of Technical Development, MGO Branch, Army Headquarters, New Delhi.

REFERENCES

1. Peirce, F.T., Rees, W.H. & Ogden, L.W. Shirley Inst. Mem. 19, 51, (1944) or J. Textile Inst., 36T, 169, (1945).
2. Tucker, J., Goodings, A.C. & Kitching, J.A. Subcommittee on protective clothing, Report No. 160,. National Research Council, Ottawa, Canada (1944).
3. Thomas, A.M. & Gent, W.L., Proceedings of Physical Society, 57, 324, (1945.)
4. Blackman, D.S. & Davies, G., C.C.I. Report No. 1095, Chemical Inspection Department, Ministry of Supply, U.K.