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RELATIONSHIP BETWEEN MEASUREMENTS OF AIR PERMEABILITY BY TWO MACHINES

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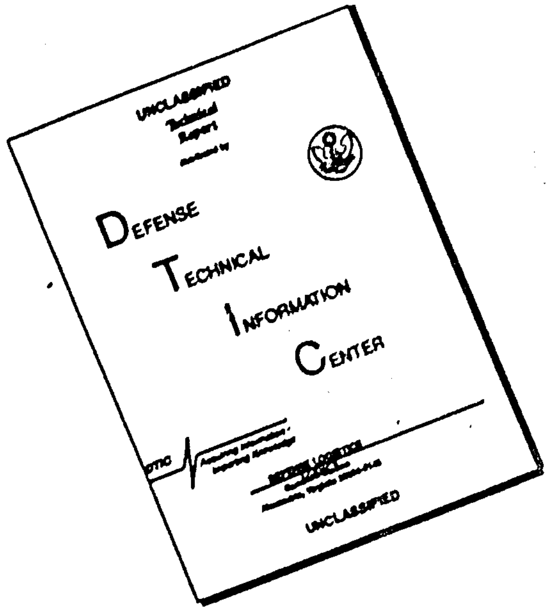

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FOREWORD

The concept of wind-resistant textiles was introduced to the armed forces with the procurement of a lightweight cotton fabric such as that worn by members of Admiral Byrd's polar expeditions. When specifications for this material were first prepared there were relatively few instruments in the textile industry for evaluating air permeability, i.e., wind resistance. The Gurley Densometer described in this report was originally developed for the testing of paper and was later adapted as an instrument to determine fabric porosity. During the latter years of the war the Frazier Air Permeameter, a machine designed by Dr. Herbert Schiefer of the National Bureau of Standards, was introduced as another method for determining this property.

As these two machines came into general use, textile manufacturers were often confronted with the problem of meeting air-permeability requirements expressed in terms of the instrument to which they did not have access. As a result of their frequent requests for information as to the relation between test results on the two machines, the Philadelphia Quartermaster Depot initiated the instrument-comparison study described in the attached paper.

STANLEY BACKER
Technologist

ABSTRACT

In this paper is described the derivation of the empirical relationship between two commonly used instruments for determining air permeability, namely the Frazier and Gurley machines. In addition, the limitations of each of the devices are discussed as well as the number of specimens necessary for testing. The correlation has also been determined by consideration of physical constants and pressure differentials, using the empirical data obtained on the Gurley and Frazier instruments operating at a pressure of 0.5 and 1.26 inches of water, respectively, as well as data obtained on the Frazier machine at the same two pressures. The equations derived were $\log Y_F = \log 533.0 - 1.02 \log X_G$, based upon the empirical data alone and $\log Y_F = \log 507.5 - \log X_G$ when the physical constants of the machines were considered.

RELATIONSHIP BETWEEN MEASUREMENTS OF AIR PERMEABILITY BY TWO MACHINES

M. I. Landsberg* and Gerald Winston**

INTRODUCTION

The warmth, water resistance, and other "comfort" characteristics of a fabric are affected by its "porosity" or "air permeability", i.e., the ability of air to pass through it.

Several instruments have been devised to measure air permeability, but the two most commonly used in government test laboratories are the Gurley Densometer and the Frazier Air Permeameter[1]. Numerous Army specifications have indicated that either or both of these machines should be used to determine the porosity of wind-resistant fabrics. However, no relationship between these apparatuses is known to have been established on a sound statistical basis. For this reason it is not possible to predict mathematically the values to be expected on one instrument by the information recorded on the other. Study of the instruments was therefore initiated to establish the following:

1. The relationship existing between the Gurley and Frazier instruments.***

2. The instrument which provides the most reproducible results and maximum sensitivity over a wide range of permeabilities for use in research or specification testing.

3. The least number of specimens necessary to obtain statistically sound data on each machine.

APPARATUS

The Gurley machines used in this investigation (Figure 1)[2] are equipped with two coaxal circular plates, at the center of each of which is a circular orifice 0.1 or 1.0 square inch in area. These plates, positioned near the base of the apparatus, are self-aligned

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***It was necessary to consider three values in all computations, inasmuch as two Gurley ratings were obtained for each fabric, depending on whether the area of the orifice used was 0.1 square inch or 1.0 square inch.

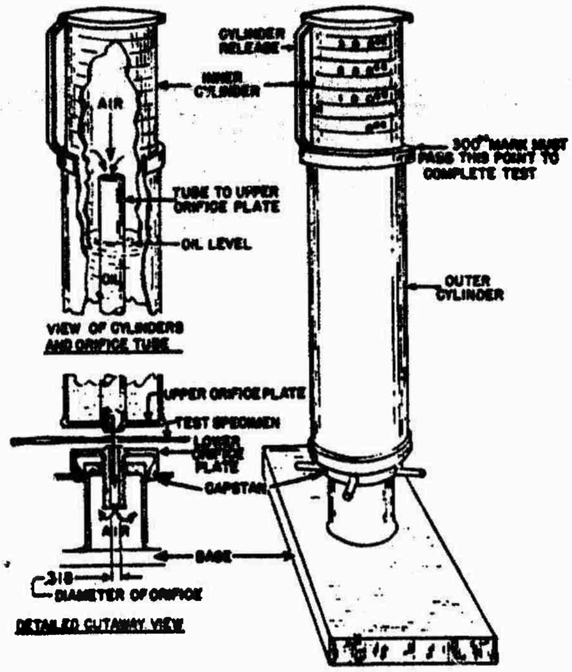

FIGURE - 1. SCHEMATIC DIAGRAM OF THE GURLEY AIR PERMEABILITY INSTRUMENT.

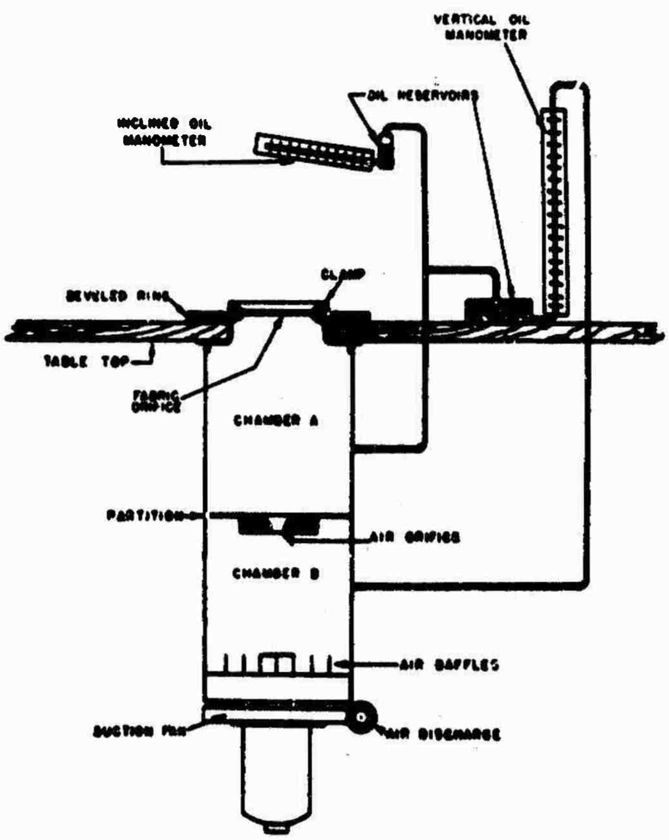

FIGURE - 2. SCHEMATIC DIAGRAM OF THE FRAZIER AIR PERMEABILITY INSTRUMENT.

so that when the fabric to be tested is fastened in place securely by means of a capstan screw clamping device no air can escape along the surface of the material. The upper plate and its opening serve, respectively, as the bottom of a cylinder and as the end of a tube which extends up through the center of the cylinder. This cylinder, 9½ inches high by 3½ inches in diameter, is filled with oil (viscosity 60-70° Saybolt at 100°F) to a prescribed point below the upper end of the tube. Air is forced through the open top of the tube by means of an inverted cylinder 9-5/8 inches high by 2-15/16 inches in diameter (with sealed top) weighing 5.0 ounces floating freely on the surface of the oil in the outer cylinder. The air pressure thus exerted is equal to 1.26 inches of water.

The outer surface of the inverted cylinder is scored off into six sections, each of which represents 50 cc. of air. The descent of this cylinder forces air through the fabric at a rate indicated by the surface markings. Air-permeability values are obtained by noting the number of seconds required for 300 cc. of air to pass through the fabric.

As can be seen from the schematic diagram (Figure 2) the Frazier instrument consists of two chambers, a suction fan, two manometers, a calibrated orifice, and a clamp for holding the specimen. Between the two chambers is mounted one of a series of nine calibrated orifices. The air in chamber B is pumped out by means of the fan and is replaced by air coming from chamber A through the orifice. The flow of air from the atmosphere into chamber A is determined by the permeability of the specimen, 0.0412 square foot of which is exposed to testing by virtue of the size of the fabric orifice. The removal of air from chamber B creates a vacuum across a tube connecting this chamber with a vertical manometer and an oil reservoir. This gauge is used to measure the pressure drop across the calibrated orifice. Still another tube connects chamber A with another reservoir and an inclined manometer. This gauge, open to the air, measures the pressure drop across the fabric.

Air permeability values are obtained by noting the vertical manometer readings while the pressure drop across the fabric is maintained at 0.5 inch of water pressure as indicated by the inclined gauge. By a consideration of the size of the calibrated orifice used, these readings can be converted into a figure which expresses the number of cubic feet of air which passes through a square foot of the fabric per minute.

DISCUSSION OF EXPERIMENTAL WORK

Ten specimens were chosen at random from each of eighteen different fabrics (Table I) varying in air permeability from 2.0 to 432.5 cubic feet per square foot per minute as measured on the Frazier instrument and from 1.3 to 197.3 seconds and from 0 to 25.3 seconds as determined by the Gurley 0.1-square inch and 1.0-square inch machines, respectively.

TABLE I

REGRESSIONAL ANALYSIS OF FRAZIER AND GURLEY (0.1-SQ. INCH AND 1.0-SQ. INCH) MACHINES

MATERIALS	ACTUAL GURLEY 0.1 SQ. IN. SECONDS	ACTUAL GURLEY 1.0 SQ. IN. SECONDS	ACTUAL FRAZIER CU. FT/SQ. FT/MIN.	ESTIMATED FRAZIER VALUES AS DETERMINED BY: GURLEY 0.1 SQ. IN. (1) $Y_F = -3.41 + \frac{550.6}{X_G}$	(2) $Y_F = 533X_G^{-1.02}$	(3) $Y_F = 570.3X_G^{-1.06}$	GURLEY 1.0 SQ. IN. (4) $Y_F = -2.03 + \frac{69.5}{X_G}$	(5) $Y_F = 66.04X_G^{-1.008}$	(6) $Y_F = 69.95X_G^{-1.2}$
OXFORD 6.8 OZ.	197.3	25.3	2.0	-.6	2.4	2.2	.7	1.9	1.5
CLOTH, CTN., UNIF. TWILL CLOTH, CTN., SATEEN	186.4	19.7	2.4	-.4	2.3	2.3	1.5	2.5	2.0
SATEEN (ZELAN TREATED)	204.8	15.8	3.2	-.7	2.3	2.1	2.4	3.2	2.8
CLOTH, CTN., SATEEN WOOL BUNTING BLUE	156.2	18.2	3.3	.1	3.1	2.8	2.5	3.3	2.7
UNIF. TWILL & DRILL CLOTH, CTN.	96.9	10.8	4.7	2.3	5.0	4.6	4.5	4.9	4.1
CLOTH, CTN., DRILL CLOTH, CTN., PADDING CANVAS	67.3	7.4	5.7	4.8	7.3	8.7	7.4	7.3	8.4
CLOTH, CTN., DRILL	64.8	7.5	7.8	8.1	7.8	7.0	7.2	7.1	8.2
CTN., UNIF. TWILL	38.5	4.4	12.8	10.9	12.9	12.1	13.8	12.9	11.8
SEERSUCKER	16.3	1.9	31.2	30.3	30.9	29.9	34.5	31.4	31.8
PADDING CTN. CANVAS	10.2	1.2	48.9	50.5	49.9	49.1	55.9	55.8	58.8
FLANNEL WOOL LINING	5.1	1.0	75.1	104.5	101.2	102.1	67.5	65.0	70.0
CLOTH, CTN., MOHAIR	5.8	*	104.1	94.7	93.7	94.2			
CLOTH, BLANKET	4.6	*	141.8	116.3	112.4	113.8			
BUNTING WOOL WHITE	2.9	*	167.6	184.4	179.9	186.3			
CLOTH, NYLON, WHITE	2.8	*	185.8	193.2	188.8	192.3			
COLLAR STIFFENING	2.1	*	220.4	258.7	250.1	260.8			
BUNTING WOOL BLUE	1.7	*	348.8	320.4	310.3	325.7			
BNTG., CTN., MERC., BR., BLUE	1.4	*	432.5	420.0	407.9	432.3			

*Too fast to record.

RELATIONSHIP	COEFFICIENT OF CORRELATION
(1) LINEAR	$r = .98$
(2) CURVILINEAR (BASED ON LOG VALUES)	$\rho = .99$
(3) CURVILINEAR (BASED ON ABSOLUTE VALUES)	
(4) LINEAR	$r = .98$
(5) CURVILINEAR (BASED ON LOG VALUES)	$\rho = .99$
(6) CURVILINEAR (BASED ON ABSOLUTE VALUES)	

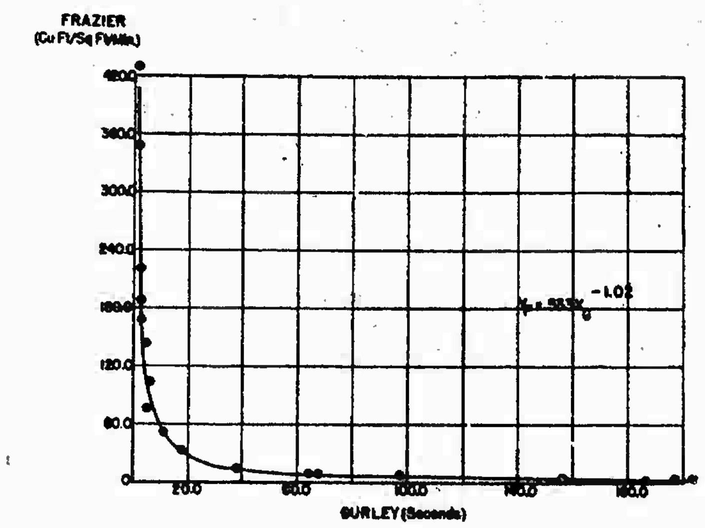

FIGURE-3. CURVILINEAR RELATIONSHIP BETWEEN THE FRAZIER & GURLEY 0.1 SQ. IN.

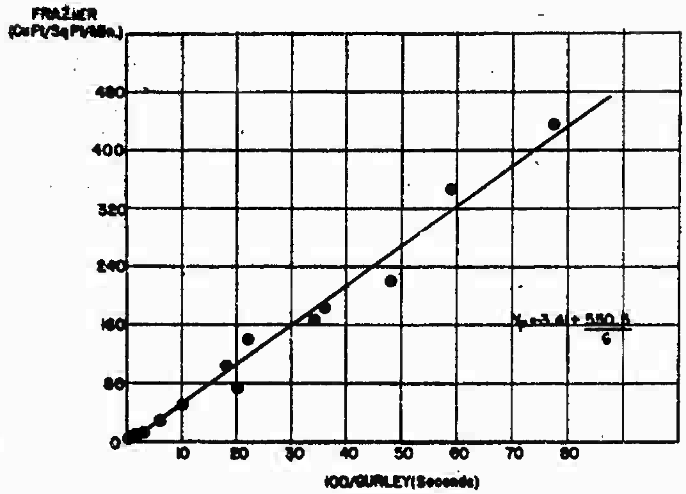

FIGURE-4. LINEAR RELATIONSHIP OF MEASUREMENTS OF AIR PERMEABILITY BY FRAZIER & RECIPROCAL OF GURLEY 0.1 SQ. IN.

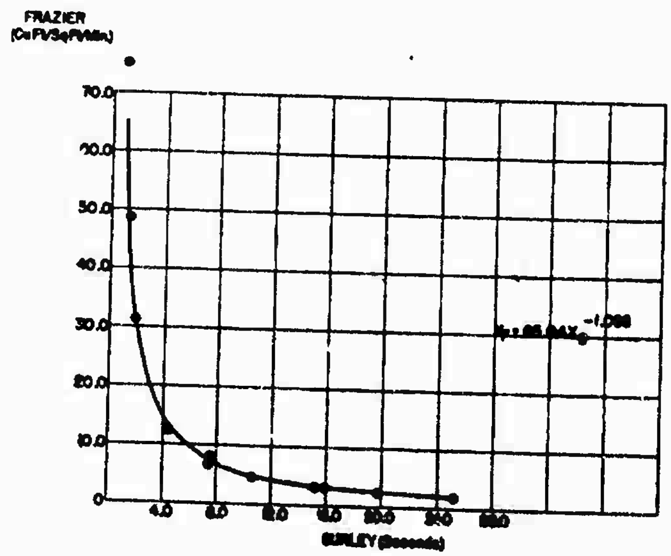

FIGURE-5. CURVILINEAR RELATIONSHIP BETWEEN THE FRAZIER & GURLEY 1.0 SQ. IN.

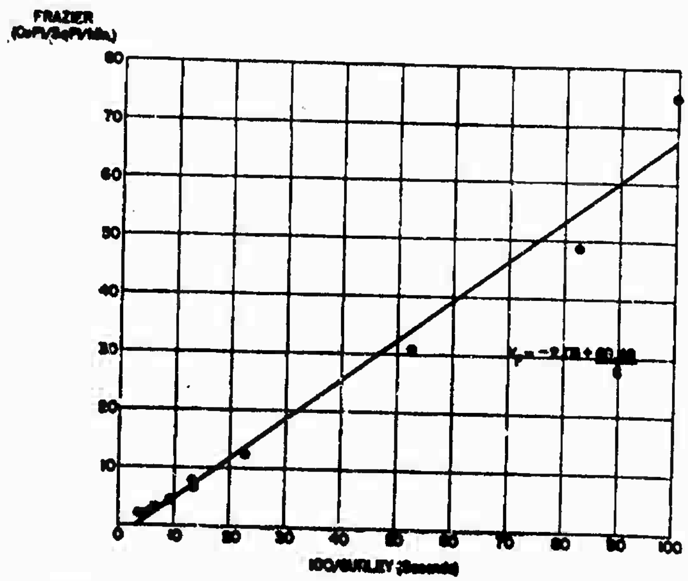

FIGURE-6. LINEAR RELATIONSHIP OF MEASUREMENTS OF AIR PERMEABILITY BY FRAZIER & RECIPROCAL OF GURLEY 1.0 SQ. IN.

The same specimens were evaluated on all three machines. It was determined statistically that there was no significant difference between results obtained in this manner and those obtained by utilizing adjacent independent specimens on each instrument. Thus it was satisfactorily demonstrated that measurement of the materials on the Frazier machine had no appreciable effect upon their porosity as indicated by subsequent Gurley measurements. Interpretations were based upon a comparison of the average values of air permeability as measured on the Frazier and Gurley apparatuses.

A regressional analysis was made establishing a curvilinear relationship between measurements made on the Frazier and those made on either of the Gurley instruments. In Table I will be found, (a) the average air-permeability values of ten specimens of the eighteen fabrics as measured on the three machines, (b) the regressional equations showing the mathematical relationship between the Frazier and the two Gurley apparatuses, and (c) a Gurley-Frazier conversion table. Consideration of these figures indicates clearly the high association between Gurley and Frazier measurements.

The points plotted in Figure 3 illustrate the curvilinear relationship existing between the average of ten determinations on each of the eighteen fabrics as measured on the Frazier apparatus and the Gurley 0.1-square-inch machine. The relationship ($Y_F = 533\ X_G^{-1.02}$) based upon a minimum difference existing between the square of the log of the actual and estimated values is indicated by the solid line. In contrast a relationship ($Y_F = 570.3\ X_G^{-1.06}$) based upon the minimum difference between the square of the actual and estimated values was computed as shown in Table I so that Frazier readings at the extreme ranges could be determined more accurately. Figure 4 has been prepared to show the linear relationship which exists when reciprocals of values as measured by the Gurley instrument are used to estimate Frazier readings. Figures 5 and 6 correspond to Figures 3 and 4 respectively, illustrating the relationship existing between measurements on the Gurley 1.0-square-inch and the Frazier machines.

To analyze the comparative variability of the three instruments, ten specimens of each of six types of Army fabrics were used. Their air-permeability values ranged from 7.8 to 141.6 cubic feet per square foot per minute by Frazier measurements and from 41.6 to 64.6 seconds, and from 1.0 to 11.6 seconds as determined respectively by the Gurley 0.1-square-inch, and Gurley 1.0-square-inch machines. Since Gurley measurements would be more widely dispersed than Frazier computations with respect to very dense fabrics and since the opposite would be true in determining the permeability of more porous materials, samples were chosen from this middle group to avoid bias in the comparison.

Determination of the most reproducible machine and the least number of samples required to obtain statistically sound data was accomplished by computing the coefficients of variation for the Frazier, Gurley 0.1-square-inch and Gurley 1.0-square-inch instruments (Table II). These

TABLE III

COMPARISON OF VARIABILITY OF AIR PERMEABILITY MEASUREMENTS ON THE FRAZIER AND GURLEY MACHINE

Fabric	Frazier $\bar{X}$ cu.ft/sq ft/min	Frazier σ	Frazier V	Gurley 0.1 sq.in. $\bar{X}$ Sec.	Gurley 0.1 sq.in. σ	Gurley 0.1 sq.in. V	Gurley 1. sq.in. $\bar{X}$ Sec.	Gurley 1. sq.in. σ	Gurley 1. sq.in. V
Cotton Drill	7.8	.64	8.3	64.6	5.70	8.8	7.5	.78	10.3
Cotton Uniform Twill	12.5	.68	5.5	38.5	3.36	8.7	4.4	.47	10.7
Seersucker	31.2	2.14	6.9	16.3	2.11	12.9	1.9	.21	10.8
Cotton Canvas Padding	48.9	4.18	8.6	10.2	1.12	11.0	11.6	.17	1.5
Flannel Wool Lining	75.1	3.81	5.1	5.1	.07	1.5	1.0	.08	8.0
Blanket	141.6	2.97	2.1	4.6	.46	10.1	1.1	.105	9.6
σ_V			1.36			1.97			1.90
$\bar{V}$			6.1			8.8			8.5

average coefficients were found to be 6.1, 8.8, 8.5, respectively. It is indicated that the variability of air-permeability values registered on the Frazier device does not differ significantly from that given by the Gurley apparatus. With the average coefficients of variation of these representative specimens as a basis, it was determined that five in lieu of ten specimens could be used, provided a 10% variation is permissible from the true mean within which the means of subsequent samples may fall. The testing of ten specimens will give results within a tolerance of 5%. It should be noted, however, that the experiments described in this report were performed only with fabrics which had been manufactured in accordance with Army specifications; it is possible that these sample sizes might prove inadequate for testing other materials whose variability was less closely controlled.

In view of the excellent correlation between the empirical data listed in Table I, an attempt was made to establish a mathematical relationship between the two apparatuses based upon their physical constants and the effect of their pressure differentials. To accomplish this the average permeability results obtained for the eighteen fabric samples on the Gurley machine (0.1 sq. in. orifice), normally expressed as seconds/300 cc./0.1 sq. in. were converted (see Column 5, Table III) to cu. ft./sq. ft./min. as follows:

$$(1) \quad \frac{300 \times 144 \times 60 \times 407.8}{(\text{Gurley reading})\ 28317 \times 0.1 \times 406.5}$$

$$(2) \quad \text{or } \frac{917.7}{\text{Gurley reading}} = \text{cu. ft./sq. ft./min.}$$

where

300 = number of cc. of air passing through the instrument in G seconds

28317 = number of cubic cm. in a cubic foot

144 = number of [illegible] inches in a square foot

0.1 = area of cloth tested in Gurley instrument

$\frac{407.8}{406.5}$ = correction factor to reduce volume of air passing through Gurley to standard conditions.

It was necessary to correct the air flow values thus obtained from the Gurley instrument in order to take into account the differences in pressure at which the two instruments operated. Use was made of Rainards[3] equation relating air flow through textile fabrics at varying pressure differentials. Rainard's average air permeabilities measured (at 0.5 inch pressure differential) on the Frazier instrument for ten specimens (Column 1, Table III) were used to predict air flow through fabrics at a pressure differential of 1.26 inches (Column 2, Table III) by use of the equation

TABLE III

AIR FLOW FOR VARIOUS FABRICS AT 0.5 AND 1.26 INCHES OF WATER PRESSURE

RAINARD[2]			PHILADELPHIA QUARTERMASTER DEPOT		
(1)	(2)	(3)	(4)	(5)	(6)
Frazier (cu.ft/sq.ft/min)			Frazier (cu.ft/sq.ft/min)	Gurley (cu.ft/sq.ft/min)	
Measured Value (0.5" water pressure)	Calculated Value* (1.26" water pressure)	Column (1) / Column (2)	Measured Value (0.5" water pressure)	Measured Value** (1.26" water pressure)	Column (4) / Column (5)
3.7	4.8	.77	2.0	4.65	.43
3.9	8.6	.45	2.4	4.92	.49
2.7	4.8	.56	3.2	4.49	.71
3.9	8.3	.47	3.3	5.88	.56
13.8	31.8	.43	4.7	9.47	.50
18.9	43.7	.43	6.7	13.64	.49
77.1	121.2	.64	7.8	14.21	.55
100.4	211.4	.47	12.5	23.84	.52
164.0	151.2	1.08***	31.2	56.30	.55
525.0	693.8	.76	48.9	89.97	.54
			75.1	179.94	.42
			104.1	166.85	.62
	Average -	.553	141.6	199.50	.71
			167.6	316.44	.53
			185.8	327.75	.57
			220.4	437.00	.50
			348.8	539.82	.65
			432.5	705.92	.61
				Average -	.553

* Using equation $F = K \Delta p^2 + P \Delta p$

** Using conversion factor $\frac{917.7}{\text{Gurley Reading}}$

*** Not included in average

(3) $F = K\Delta p^2 + P\Delta p$

where F = rate of air flow (cu. ft./sq. ft./min.)

Δp = pressure differential producing this air flow

K = slope of line relating $\frac{F}{\Delta p}$ to pressure

P = limiting value of $\frac{F}{\Delta p}$ as Δp approaches zero.

The ratios of air flow at the two pressure differentials (indicated in Column 3, Table III) fell within a narrow range except for fabric number 9 which was eliminated from consideration by use of Chauvenet's Criterion. Excluding this one value, the average ratio was computed to be .553.

A similar set of ratios was computed for the air flow measurements conducted at the Philadelphia Quartermaster Depot on both Gurley and Frazier instruments, operating at pressures of 1.26 and 0.5 inches, respectively. These are listed in Column 6 of Table III. The average ratio in this case was found to be .553. The agreement of the average ratios of air flow at the two different pressure differentials when based upon the Rainard and the Philadelphia data warranted use of the factor .553 in the establishment of the conversion equation which takes into consideration the effects of different pressures:

(4) $\text{Frazier reading} = \frac{917.7^{*} \times .553}{\text{Gurley reading}} = \frac{507.5}{\text{Gurley reading}}$

or (5) Log (Frazier reading) = log 507.5 - log (Gurley reading).

Equation (5) is plotted (dotted line in Figure 7) together with the data obtained by testing the eighteen fabrics on both the Gurley and the Frazier machines (Columns 1 and 3 of Table I). The similarity of the curve (solid line) based upon the actual laboratory data ($\log Y_F = \log 533.0 - 1.02 \log G$) and the curve based upon equation (5) indicated that the two equations are identical for all practical purposes. Figure 8 furnishes the same conclusion with respect to data obtained on the Gurley 1.0 sq. in. machine.

CONCLUSIONS

A curvilinear relationship exists between measurements made on the Frazier machine and on either of the Gurley apparatuses. Considering the physical constants of the two instruments and taking into account the effect of pressure differential it is possible to predict Frazier air-permeability values from measurements made on the Gurley machine.

* Reference Table III: $\frac{\text{column 4}}{\text{column 5}}$ = column 6.

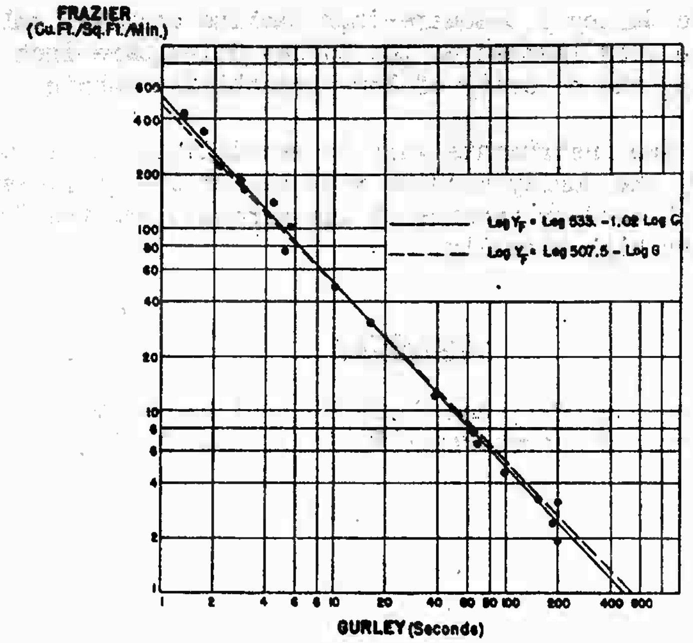

FIGURE-7. RELATIONSHIP BETWEEN FRAZIER & GURLEY 0.1 SQ. IN.

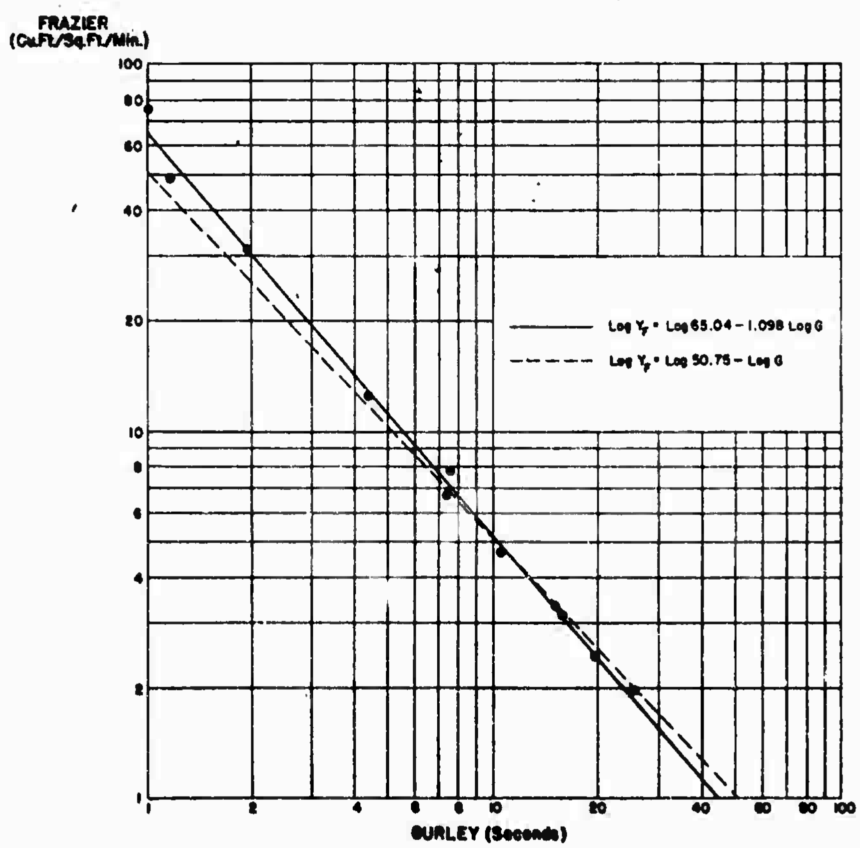

FIGURE-8. RELATIONSHIP BETWEEN FRAZIER & GURLEY 1.0 SQ. IN.

Although the Gurley 1.0-square-inch machine operates only in a limited range, it may be used instead of the Gurley 0.1-square-inch device to save time in measuring the porosity of low-permeability fabrics.

Because the two instruments vary in sensitivity at different levels of permeability, the Gurley machine with either 0.1 or 1.0-square-inch orifice should be used on fabrics of low porosity and the Frazier on materials of very high porosity.

REFERENCES

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(2) U. S. Army Specifications 100-48.

(3) Rainard, L. W., Air Permeability of Fabrics - Textile Research Journal - Oct. 1946, P. 473.

ACKNOWLEDGEMENTS

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2. Mr. Roger Kelly whose calculations led to the derivation of the formula

$$F = \frac{507.5}{\text{Gurley Reading}}$$

3. Mr. Norman E. Roberts who reviewed and offered editorial comments on this paper.