Designation: D7984 – 21

Standard Test Method for Measurement of Thermal Effusivity of Fabrics Using a Modified Transient Plane Source (MTPS) Instrument[1]

This standard is issued under the fixed designation D7984; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This standard provides a test method for measuring the thermal effusivity of fabrics under still air conditions. Other standards, Test Methods F1868 and D1518, measure the thermal insulation of materials under steady-state conditions; however, this test method is used to measure transient heat exchange between a fabric specimen and a heated surface. It has been established that there is a strong positive correlation between the thermal effusivity and the initial perceived coldness between human skin and different materials.[2,3]

1. Scope

1.1 This test method covers the quantitative measurement of thermal effusivity of woven, knitted, or non-woven fabrics using a guarded modified transient plane source (MTPS) instrument.[4] This test method is applicable to a wide range of thicknesses; however, the thickness of the specimen must be greater than the penetration depth of the heat flux during the measurement time.

1.2 This test method is comparative since specimens of known thermal effusivity are used to calibrate the apparatus at the factory level. Thermal effusivity of the calibration specimens are confirmed through calculations that use established properties of thermal conductivity, density, and specific heat.

1.3 This test method is intended for measuring fabrics in a dry state at ambient conditions.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[5]

D123 Terminology Relating to Textiles

D1518 Test Method for Thermal Resistance of Batting Systems Using a Hot Plate

D1776 Practice for Conditioning and Testing Textiles

D4920 Terminology Relating to Conditioning, Chemical, and Thermal Properties

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

F1868 Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

[1] This test method is under the jurisdiction of ASTM Committee D13 on Textiles and is the direct responsibility of Subcommittee D13.51 on Conditioning, Chemical and Thermal Properties.

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[2] Marin, E., "Teaching Thermal Physics by Touching," *Latin-American Journal of Physics Education*, Vol 2, No. 1, January 2008, pp. 15-17.

[3] Wongsriruska, S., Howes, P., Conreen, M., Miodownik, M., "The Use of Physical Property Data to Predict the Touch Perception of Materials," *Materials and Design*, Vol 42, 2012, pp. 238-244.

[4] The sole source of supply of the TCi instrument known to the committee at this time is C-Therm Technologies, Ltd., C/O RPC, 921 College Hill Rd., Fredericton, New Brunswick, Canada, E3B 6Z9. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[5] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.1 *modified transient plane source (MTPS), n*—an apparatus that has a one sided planar heat source and a guard, or guard ring, mounted perpendicular to the planar heat source, that is put in contact with one side of a test specimen, so that a short duration heat pulse can penetrate into the specimen.

3.1.1.1 *Discussion*—The purpose of the guard (or guard ring) is to maintain a consistent unidirectional heat flow across the test specimen.

3.1.2 *penetration depth, n*—the functional depth to which the initial radiation applied at the surface travels into the specimen.

3.1.2.1 *Discussion*—To ensure that the heat wave is contained within the test specimen, the thickness of the test specimen must be greater than the penetration depth.

3.1.3 *thermal effusivity, n*—a material property that describes its ability to exchange thermal energy with another material with which it is in contact.

$$e = \sqrt{\lambda \cdot c_p \cdot \rho} \quad (1)$$

where:

e = thermal effusivity, $W \cdot S^{1/2}/(m^2 \cdot K)$,
λ = thermal conductivity, $W/(m \cdot K)$,
c_p = specific heat capacity, $J/(kg \cdot K)$, and
ρ = mass density, kg/m^3.

3.1.3.1 *Discussion*—The thermal effusivity of two materials that are in contact determines the temperature at their interface as a result of heat energy exchange.

3.2 For definitions of other textile terms used in this test method refer to Terminology D123.

3.3 For definitions of other terms related to conditioning, chemical and thermal properties used in this test method, refer to Terminology D4920.

4. Summary of Test Method

4.1 A constant momentary heat pulse is applied to the surface of a test specimen. The heat pulse elevates the temperature of the surface as the heat diffuses into the test specimen in one dimensional heat flow. Thermal effusivity is determined from the temperature increase at the surface of the material with elapsed time. The temperature increase at the surface is inversely proportional to the thermal effusivity of the sample material.

5. Significance and Use

5.1 This test method measures the rate of thermal transport between a heating element and a fabric specimen. Some of the comfort properties of a garment relate to initial thermal sensations (that is, cold or warm feeling upon initial contact), where lower thermal effusivity values indicate sensations of warmth and higher values indicate sensations of coolness. The thermal effusivity of different fabrics and their initial perceived surface temperature are important to assist product developers with fabric selection.

5.2 The sensor and the test specimen being measured shall be at the same temperature for measurements at standard conditions. This test method may be applied to any fabric with a thermal effusivity in the range of 35 to 1700 $Ws^{1/2}/m^2 \cdot K$.

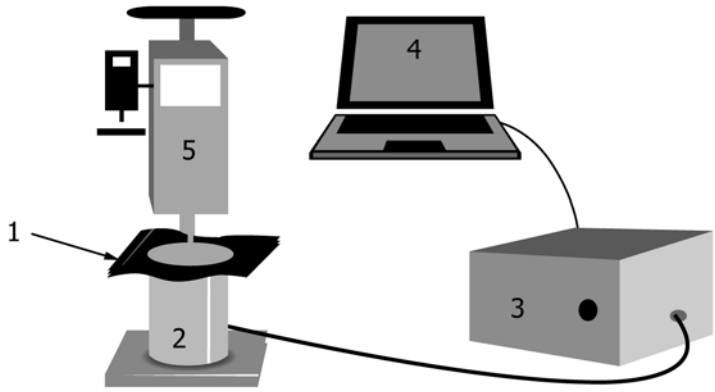
5.3 Air flow shall be kept at a minimum to ensure temperature fluctuations do not occur during the measurement.

6. Apparatus

6.1 *Modified Transient Plane Source Apparatus*—See 1. The essential instrumentation required to provide the minimum transient plane source capability for this test method includes:

6.1.1 *Heater,* to provide a heat pulse to one surface of the test specimen sufficient to cause the surface temperature of the specimen to increase 1 to 3°C.

6.1.2 *Temperature sensor,* to provide an indication of the surface temperature of the test specimen readable to within ±0.01°C.



(1) Fabric Specimen
(2) Heater and Sensor
(3) Controller
(4) Data Acquisition System
(5) Constant Pressure Applicator

FIG. 1 Basic Layout of an Effusivity Measurement Apparatus

6.1.3 *Temperature programmer,* capable of providing a power pulse of 1 to 3 s to the heater resulting in an increase in the specimen surface temperature of 1 to 3°C.

6.1.4 *Heated guard ring,* or other device to ensure a unidirectional heat flow in the test specimen perpendicular to the heated surface.

6.1.5 *Data acquisition device,* to provide a means of acquiring, storing, and displaying measured or calculated signals, or both, with a digital acquisition rate of 20 data points per second or greater. The minimum output signals required are temperature or temperature rise and time.

6.1.6 Auxiliary instrumentation considered necessary or useful for conducting this test method include:

6.1.6.1 *Data analysis capability,* to perform the necessary calculations to derive the property of thermal effusivity from the temperature and time experimental variables.

6.2 *Load device,* to apply a fixed controlled force of 10 to 50 kPa to the specimen to ensure that the test specimen is in intimate contact with the heater and temperature sensor.

7. Preparation of Test Specimens

7.1 *Specimen Preparation*—Cut specimens so that the sensor area is covered completely. Take a minimum of five specimens from each sample to be tested. Specimens shall be staggered in such a manner that no two specimens contain the same yarns. The specimens need to be thicker than 1.0 mm so that the heat wave does not penetrate beyond its maximum test penetration of 1.0 mm thickness during the sampling period. That thickness ensures that even if the fabric is on the higher end of the thermal effusivity range, the penetration depth of the heat flux during the measurement time is maintained within the fabric.

8. Conditioning

8.1 Maintain the room condition as directed in Practice D1776.

8.2 Bring the test specimens to moisture equilibrium for testing as directed in Practice D1776. It is necessary to equalize the temperatures of the sensor and the specimen by placing them in the same location.

NOTE 1—A repeat sensor temperature measurement before the test may verify the equalization and sensor stabilization.

9. Calibration

9.1 Prepare the instrument for operation and perform any instrument calibrations according to the operations manual.

9.2 Select a industry reference material of known thermal effusivity (e_r).

NOTE 2—The instrument operations manual may offer suggestions for suitable industry reference materials.

9.3 Determine the thermal effusivity of the industry reference material according to Section 10 and confirm measured values are within ±5 % of the expected value for the material.

10. Procedure

10.1 Place sufficient layers of the fabric test specimen over the heater surface so that the heater is completely covered and that a total specimen thickness of more than 1.0 mm is achieved. Rotate each fabric layer by about 30° from those above and below so that no layer is aligned with the adjacent one.

10.2 Select and apply a fixed load of between 10-50 kPa to the fabric layers on the side opposite to the heater to ensure intimate contact with the heater.

10.3 Initiate the experiment. Provide a constant momentary power pulse to the heater and guard ring so that a temperature rise of 1 to 3°C occurs at the surface of the test specimen within 1 to 3 s.

NOTE 3—The temperature increase at the surface is inversely proportional to the thermal effusivity of the sample material. A scouting run may be used to determine the optimal power and timing perimeters. Alternatively, instrument operations manual may recommend specific power levels.

10.4 Record the thermal effusivity (e_o).[6]

10.5 Allow the test specimen and apparatus to cool to ambient temperature.

NOTE 4—This normally takes less than 1 min.

10.6 Repeat the thermal effusivity measurement according to steps 10.3 – 10.5 on each specimen two additional times.

10.7 Repeat steps 10.1 – 10.6 for the additional four specimens.

11. Calculation

11.1 Average data from all five specimens to determine the average thermal effusivity values and standard deviation for the fabric samples.

12. Report

12.1 Report the following information:

12.1.1 Identification of the material tested,

12.1.2 Identification of the calibration materials and timing perimeters employed in the calibration (test time, calculated start time, cooling period, frequency, power level, and temperature),

12.1.3 Temperature and relative humidity of the test environment,

12.1.4 Sensor temperature,

12.1.5 The side of each specimen that was applied against the sensor,

12.1.6 The thermal effusivity of each specimen, the average thermal effusivity, and standard deviation of all specimens of one fabric type,

12.1.7 The test time applied to the measurement pulse,

12.1.8 Applied force used with the compression test accessory and sample thickness.

13. Precision and Bias

13.1 The precision of this test method is based on an interlaboratory study (ILS) of Test Method D7984, conducted

[6] "Thermal Conductivity 28/Thermal Expansion 16, with R. Dinwiddie, M. A. White, and D. L. McElroy, eds., DEStech Publishing, Lancaster PA, 2005, pp. 256-268.

during 2018 and 2019. Seventeen data sets from seven laboratories were submitted to this study, which tested three fabrics at two different levels of compression. Every "test result" represents an individual determination, and is an average of five measurements in a given location. The laboratory reported three replicate test results for each material at each compression level. Practice E691 was followed for the design and analysis of the data; the details are given in a Research Report.[7]

13.1.1 *Repeatability (r)*—The pooled repeatability relative standard deviation was 1.5 %. At the 95 % confidence level, no significant difference exists between two test results on the same material in the same laboratory if the value between the two differs by less than a factor of 0.042*x* (4.2 %), where *x* is total test value.

13.1.1.1 Repeatability can be interpreted as maximum difference between two results, obtained under repeatability conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

13.1.2 *Reproducibility (R)*—The pooled reproducibility relative standard deviation was 5.4 %. At the 95 % confidence level, no significant difference exists between two test results on the same material between different laboratories if the value between the two differs by less than a factor 0.15*x* (15 %), where *x* is the total test value.

13.1.2.1 Reproducibility can be interpreted as maximum difference between two results, obtained under reproducibility conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

13.1.3 *Gauge Repeatability and Reproducability*—The relative gauge repeatability and reproducibility of the ILS was 5.6 %

13.1.3.1 The gauge repeatability and reproducibility statistic can be understood as a measure of the overall variability of the method and is often used to flag test results in inter-laboratory comparisons which may be in excess of the variability inherent to the method.

13.1.4 The preceding terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

13.2 *Bias*—At the time of the study, there was no accepted industry reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

14. Keywords

14.1 fabrics; heat transfer; modified transient plane source; textiles; thermal effusivity

[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D13-2000. Contact ASTM Customer Service at service@astm.org.

APPENDIX

(Nonmandatory Information)

X1. MEASUREMENT UNCERTAINTY

X1.1 *General*—There are, in general, two types of errors (sometimes called measurement uncertainties), offset and variation. Offset errors (also named systematic or bias errors) affect the accuracy of the measurement while the variation (also named random or imprecision) affects the repeatability of the measurement. Errors in MTPS thermal effusivity measurements have four significant sources: variations in the specimen under test, quality of contact between sensor and specimen, errors from equipment, and errors from the calibration.

X1.2 *Material*:

X1.2.1 Variations between specimens may change the system heat transfer characteristics. An example of this is the humidity content in the specimen. Water has higher thermal effusivity, and therefore, change in humidity content may significantly change the thermal effusivity results for fabric materials.

NOTE X1.1—In characterizing fabrics, it can be of specific interest to determine the impact of moisture content on the thermal properties of the material. Water in itself is not inherently a source of error as long as it is intentionally desired to characterize such impact and is controlled. Any addition of moisture to the test specimen or modifications to the environmental relative humidity must be recorded in the test report.

X1.2.2 Variation within the environmental or specimen temperature is another factor that can impact the thermophysical properties of a particular specimen. Similar to the example of water in Note X1.1, this material variation is not treated as a measurement error but rather as the measured characteristic of the specimen under the given specific conditions. The user must be attentive to material variations when considering measured results as they may affect both the precision and the accuracy of the measurement.

X1.3 *Contact Resistance*—The quality of contact between the sensor surface and the fabric specimen is critical to having accurate and repeatable measurements. For testing of textiles and foams, the sensor to sample contact should be free of water. In addition, the use of the compression test accessory during application of pressure to the fabric/sensor interface is encouraged, as it ensures that errors associated with variations in contact resistance are minimized, making the results repeatable. It is also essential to ensure that test specimens and the sensor are stabilized in the desired environment. It is important to ensure that the temperature differential between test specimens and the sensor is maintained at or below 1.5°C. If not, heat will transfer from specimens to the sensor, yielding faulty test results. Contact resistance and temperature differentials may affect both the precision and accuracy of the measurement.

X1.4 *Equipment*—Equipment errors may originate from variations in: (1) current source as a result of changes in

environment temperature and other conditions (short-term drift), (2) current source as a result of long-term drift, (3) sensor resistance (and hence supplied power) during the transient measurement, (4) sensor resistance (and hence supplied power) as a result of initial sensor temperature, and (5) additional errors may come from voltage measurement circuitry.

X1.5 *Calibration*—The MTPS calibration curves are based on calibration samples, which need to be characterized for thermal conductivity, density, and specific heat capacity. Users can obtain certified materials with values for thermal conductivity from the National Institute of Standards and Technology (NIST)[8] and the National Physical Laboratory (NPL).[9] Using these certified materials and their measured volumetric mass density and specific heat, their thermal effusivity can be determined using Eq 1. These materials can be used as industry reference materials for calibration or validation, or both, of the apparatus used in this test method. Since these values have accuracy errors of a few percentage points, these errors are naturally transferred to the MTPS sensor. The overall accuracy of the calibration depends also on the linearity achieved between all the calibration samples (that is, the correlation factor F^2). For a detailed evaluation of how effusivity is determined through a calibration method, see reference.[6]

X1.6 *Major Contributing Error Estimate*—The major contributor to the accuracy error is the calibration, estimated at ≤5 %. Since the random errors contributing to the inaccuracy are not correlated, the overall accuracy error is the root of the sum of the squares of the contributors.

[8] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

[9] Available from National Physical Laboratory (NPL), Teddington, Middlesex, United Kingdom, TW11 OLW.