



Designation: **E1877–15** E1877 – 17

Standard Practice for Calculating Thermal Endurance of Materials from Thermogravimetric Decomposition Data¹

This standard is issued under the fixed designation E1877; 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.

1. ~~Scope~~ Scope*

1.1 This practice describes the determination of thermal endurance, thermal index, and relative thermal index for organic materials using the Arrhenius activation energy generated by thermogravimetry.

1.2 This practice is generally applicable to materials with a well-defined thermal decomposition profile, namely a smooth, continuous mass change.

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

1.4 There is no ISO standard equivalent to this practice.

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 and health 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:*²

[E1641 Test Method for Decomposition Kinetics by Thermogravimetry Using the Ozawa/Flynn/Wall Method](#)

[E2550 Test Method for Thermal Stability by Thermogravimetry](#)

[ASTM E1877-17](#)

<https://standards.iteh.ai/catalog/standards/sist/64c400d5-f897-4727-b91b-328a1e880120/astm-e1877-17>

¹ This practice is under the jurisdiction of Committee [E37](#) on Thermal Measurements and is the direct responsibility of Subcommittee [E37.10](#) on Fundamental, Statistical and Mechanical Properties.

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² 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.

*A Summary of Changes section appears at the end of this standard

E2958 Test Methods for Kinetic Parameters by Factor Jump/Modulated Thermogravimetry

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *failure, n*—change in some chemical, physical, mechanical, electrical or other property of sufficient magnitude to make it unsuitable for a particular use.

3.1.2 *failure temperature (T_f), n*—the temperature at which a material fails after a selected time.

3.1.3 *thermal index (TI), n*—the temperature corresponding to a selected time-to-failure.

3.1.4 *relative thermal index (RTI), n*—the temperature corresponding to a selected time-to-failure when compared with that of a control with proven thermal endurance characteristics.

3.1.4.1 Discussion—

The *TI* and *RTI* are considered to be the maximum temperature below which the material resists changes in its properties over a selected period of time. In the absence of comparison data for a control material, a thermal endurance (time-to-failure) of 60 000 h has been arbitrarily selected for measuring *TI* and *RTI*.

3.1.5 *thermal endurance, n*—the time-to-failure corresponding to a selected temperature. Also known as thermal lifetime or time-to-failure.

4. Summary of Practice

4.1 The Arrhenius activation energy obtained from other Test Methods (such as Test Methods **E1641** and **E2958**, etc.) is used to construct the thermal endurance curve of an organic material from which an estimate of lifetime at selected temperatures may be obtained.

5. Significance and Use

5.1 Thermogravimetry provides a rapid method for the determination of the temperature-decomposition profile of a material.

5.2 This practice is useful for quality control, specification acceptance, and research.

5.3 This test method is intended to provide an accelerated thermal endurance estimation in a fraction of the time require for oven-aging tests. The primary product of this test method is the thermal index (temperature) for a selected estimated thermal endurance (time) as derived from material decomposition.

5.4 Alternatively, the estimated thermal endurance (time) of a material may be estimated from a selected thermal index (temperature).

5.5 Additionally, the estimated thermal endurance of a material at selected failure time and temperature may be estimated when compared to a reference value for thermal endurance and thermal index obtained from electrical or mechanical oven aging tests.

5.6 This practice shall not be used for product lifetime predications unless a correlation between test results and actual lifetime has been demonstrated. In many cases, multiple mechanisms occur during the decomposition of a material, with one mechanism dominating over one temperature range, and a different mechanism dominating in a different temperature range. Users of this practice are cautioned to demonstrate for their system that any temperature extrapolations are technically sound.

6. Calculation

6.1 The following values are used to calculate thermal endurance, estimated thermal life and failure temperature.

6.1.1 The following definitions apply to **6.1 – 6.4**:

6.1.1.1 E = Arrhenius activation energy (J/mol),

NOTE 1— E may be obtained from another methods (such as Test Methods **E1641** and **E2958**, etc.).

6.1.1.2 R = universal gas constant (= 8.31451 J/(mol K)),

6.1.1.3 β = heating rate (K/min),

NOTE 2— β may be obtained from Test Method **E2550** and is typically 5 K/min.

6.1.1.4 TI = thermal index (K),

6.1.1.5 a = Doyle approximation integral (taken from **Table 1**);

6.1.1.6 α = constant conversion failure criterion;

6.1.1.5 t_f = estimated thermal endurance (thermal life) for a constant conversion (α) taken as the failure criterion (min),

6.1.1.6 T_c = failure temperature taken as temperature for the point of constant conversion for β (K) obtained from Test

Method **E2550** or **E2958**,

6.1.1.7 RTI = Relative Thermal Index (K),

6.1.1.8 $\sigma\sigma E$ = standard deviation in activation energy (J/mol) obtained from Test Methods **E1641** and **E2958**, etc.,

NOTE 3—The precision of the calculation in this practice are exponentially dependent on the uncertainty of activation energy value used. Care should be taken to use only the most precise values of E .

6.1.1.9 TI = thermal index (K),

6.1.1.10 σTI = standard deviation of the thermal index (K),

6.1.1.11 σRTI = standard deviation of the relative thermal index (K),

6.1.1.12 σt_f = standard deviation of the thermal endurance (min),

6.1.1.13 t_r = reference value for thermal endurance (min), and

6.1.1.14 T_r = reference value for thermal index (K).

6.2 *Method 1 – Thermal Index:*

6.2.1 Using the activation energy (E) and failure temperature (T_c), determine the value for E/RT_c .

6.2.2 Using the value of E/RT_c , determine the value for the Doyle approximation integral (aTI) by interpolation using **Eq 1** in **Table 1**.

6.2.3 Select the thermal endurance (t_f) and calculate its logarithm.

6.2.4 Substitute the values for $E, R, \log(t_f), \log(E/RT_c)$ and $a\beta$ into **Eq 1** to obtain the thermal index (TI) **(31)**.³

$$TI = E / \{ 2.303 R [\log(t_f) - \log\{E/R\beta\} + a] \} \quad (1)$$

$$TI = \{ E / (2.303 R) \} / \{ \log [100.4 t_f \beta R / E] + 0.463 E / R T_c \} \quad (1)$$

6.2.5 Determine the relative standard deviation ($\sigma TI/TI$) using **Eq 2**.

$$\sigma TI/TI \approx 1.2 \sigma E/E \quad (2)$$

$$\sigma TI/TI \approx \pm 0.19 \sigma E/E \quad (2)$$

6.2.6 Report the thermal index (TI) and its relative standard deviation ($\sigma TI/TI$) along with the thermal endurance (t_f).

6.3 *Method B – Thermal Endurance Curve:*

6.3.1 Arbitrarily select two or three temperatures in the region of interest and calculate the corresponding logarithm of the thermal endurance ($\log[t_f]$) values at each temperature using **Eq 3**.

$$\log[t_f] = E / (2.303 R T) + \log[E / (R \beta)] - a \quad (3)$$

$$\log[t_f] = (E / 2.303 R T_c) + \log[E / 100.4 R \beta] - 0.463 E / R T_c \quad (3)$$

6.3.2 Prepare a display of logarithm of thermal endurance on the ordinate versus the reciprocal of absolute temperature on the abscissa (see **Fig. 1**).

6.3.3 Alternative thermal indexes (TI) and associated logarithm of thermal endurance ($\log[t_f]$) may be estimated from this display.

6.3.4 The standard deviation in the thermal endurance (t_f) may be estimated using **Eq 4**.

$$\sigma t_f / t_f = (1 - 0.052 E / R T) \times (\sigma E / E) \quad (4)$$

$$\sigma \log[t_f] / \log[t_f] \approx \pm \sigma E / E \quad (4)$$

6.3.5 From the law of propagation of uncertainties **(2)**:

$$\sigma t_f / t_f = 2.303 \log[t_f] \sigma E / E \quad (5)$$

6.4 *Method C – Relative Thermal Index:*

6.4.1 Relative Thermal Index may be determined from the activation energy determined by thermogravimetry and the thermal index obtained by some other method (such as electrical or mechanical tests) using **Eq 56**.

$$RTI = ER [\ln[t_f] - \ln[t_r] + E / (R T_r)] \quad (6)$$

$$RTI = E / R [\ln[t_f] - \ln[t_r] + E / (R T_r)] \quad (6)$$

6.4.2 The relative standard deviation of the relative thermal index ($\sigma RTI/RTI$) is estimate from **Eq 6** where the reference values of thermal endurance (t_r) and corresponding reference temperature (T_r) are considered to be exact.

$$\sigma RTI/RTI = 1.4 \sigma E/E \quad (6)$$

7. Report

7.1 Report the following information:

7.1.1 The value, standard deviation (or relative standard deviation), and source for each value used in the determination;

7.1.2 Designation of the material under test, including the name of the manufacturer, the lot number, and supposed chemical composition when known; and

³ The boldface numbers in parentheses refer to a list of references at the end of this standard.

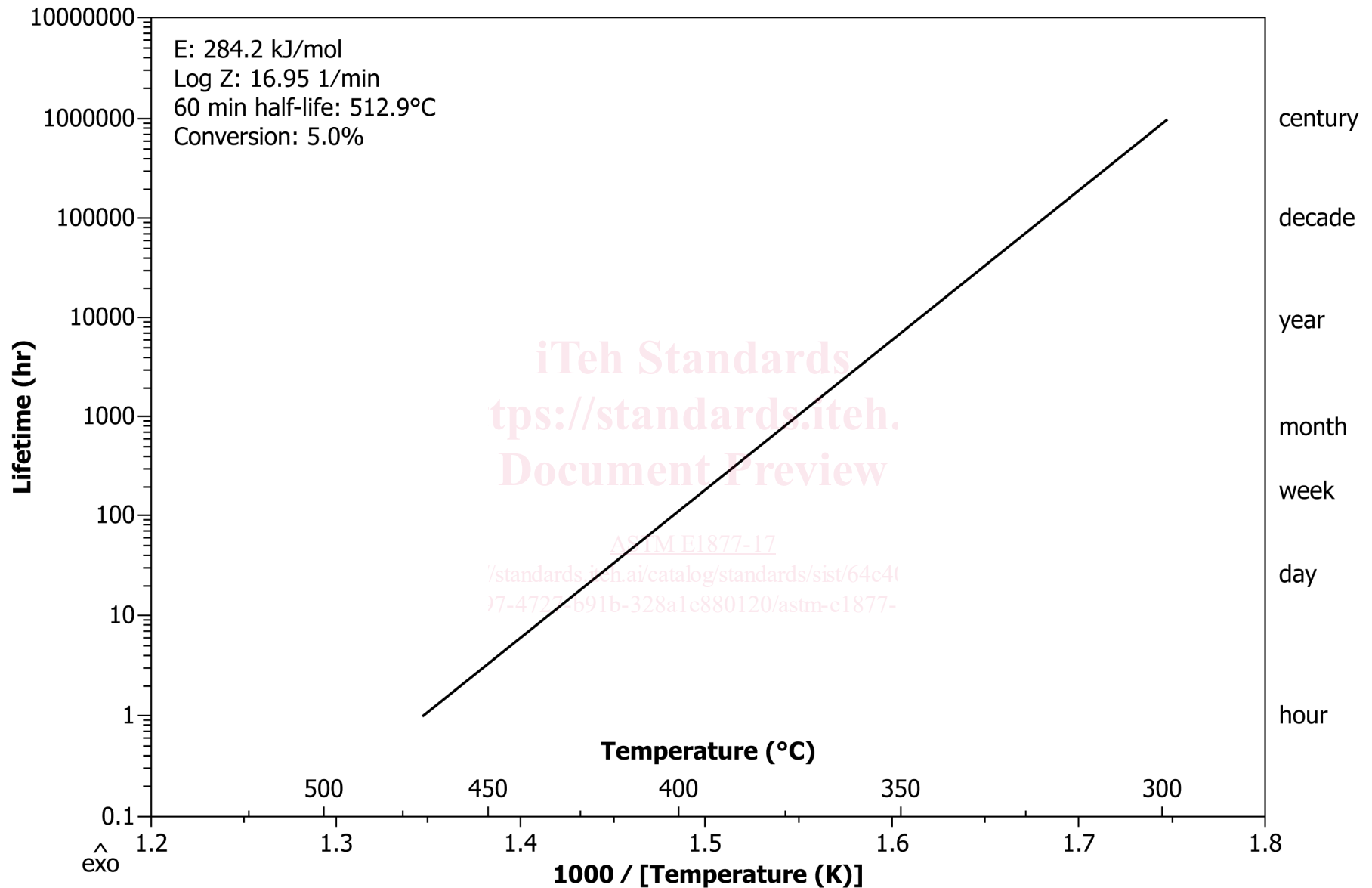


FIG. 1 Thermal Endurance Curve

7.1.3 The calculated thermal index (TI) and its relative standard deviation ($\sigma TI/TI$) or relative thermal index (RTI) and its relative standard deviation ($\sigma RTI/RTI$) along with the identified thermal endurance.

7.1.3.1 *Example—Example:*

$$TI(60\ 000\ \text{hr}) = 453 \pm 6\ \text{K}(180 \pm 6^\circ\text{C})$$

7.1.4 The specific dated version of this practice that is used.

8. Precision and Bias⁴

8.1 The precision and bias of these calculations depend on the precision and bias of the kinetic data used in them. To provide an example of the precision expected, thermal index was calculated by the procedure in this practice using data for poly(tetrafluoroethylene) from the interlaboratory study conducted to develop the precision and bias statement for Test Method E1641. Extreme values of thermal life were calculated using an arbitrarily chosen value for temperature of 600 K and the extreme values of E corresponding to the 95 % confidence level from that interlaboratory study. The resulting calculated extreme values were 9 years and 3700 years for this material.

9. Keywords

9.1 Arrhenius activation energy; Arrhenius pre-exponential factor; kinetic parameters; relative thermal index; thermal decomposition; thermal endurance; thermal life; thermogravimetric analysis

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE CALCULATIONS

X1.1 Example Calculations for the Values Determined in This Standard

X1.1.1 Example data obtained from Test Method E1641 includes:

X1.1.1.1 $E = 320\ \text{kJ/mol} = 320\ 000\ \text{J/mol}$

X1.1.1.2 $\sigma E = 24\ \text{kJ/mol} = 24\ 000\ \text{J/mol}$

X1.1.1.3 $R = 8.31451\ \text{J/(mol K)}$

X1.1.1.4 $\beta = 5.0\ \text{K/min}$

X1.1.2 Example data obtained from Test Method E2550 includes:

X1.1.2.1 $T_c = 783\ \text{K}$

X1.1.2.2 $\sigma T_c = 6\ \text{K}$

X1.1.3 Arbitrarily selected:

X1.1.3.1 $t_f = 60\ 000\ \text{hr} = 3\ 600\ 000\ \text{min} = 6.8\ \text{yr}$

X1.1.3.2 $T_r = 683\ \text{K}$

X1.1.3.3 $t_r = 100\ 000\ \text{hr} = 6\ 000\ 000\ \text{min} = 11\ \text{yr}$

⁴ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E37-1024. Contact ASTM Customer Service at service@astm.org.

X1.2 Example Calculations for Thermal Index (TI)

X1.2.1 Determine the value for E/RT from values in X1.1.1.1, X1.1.1.3, and X1.1.2.1:

$$E/RT = (320\,000 \text{ J/mol}) / [8.31451 \text{ J/(mol K)} \times 783 \text{ K}] = 49.1532$$

$$E/RT = (320\,000 \text{ J/mol}) / [8.31451 \text{ J/(mol K)} \times 783 \text{ K}] = 49.1532$$

X1.2.2 Using the value of E/RT from X1.2.1, determine the value for a by interpolation in Table 1:

$$a = 24.7471$$

X1.2.2 Substitute values from X1.1.1.1, X1.1.1.3, X1.1.1.4, X1.1.3.1, and X1.2.2 into Eq 1:

$$\begin{aligned} TI &= E / (2.303 R \{ [\log [t_r] - \log [E / (R \beta)]] + a \}) \\ &= \{ 320\,000 \text{ J/mol} / (2.303 \times 8.314 \text{ J/(mol K)}) \} \\ &\quad \{ \log [3.6 \times 10^6 \text{ min}] \\ &\quad - \log [320\,000 \text{ J/mol} / (8.31451 \text{ J/(mol K)}) \times 5 \text{ K/min}] \\ &\quad - 24.7471 \} \\ &= \{ 16\,712 \text{ K} \} \{ 6.5563 - \log [7697.39/\text{min}] - 24.7471 \} \\ &= 16\,712 \text{ K} \{ 6.5563 - 3.8863 - 24.7471 \} \\ &= 16\,712 \text{ K} / 27.4171 \\ TI &= 609.5 \text{ K} = 336.3 \text{ }^\circ\text{C} \end{aligned}$$

$$\begin{aligned} TI &= \{ E / (2.303 R) \} \{ \log [100.4 t_r \beta R / E] + 0.463 E/RT \} \\ &= \{ 320\,000 \text{ J mol}^{-1} / (2.303 \times 8.314 \text{ J mol}^{-1} \text{ K}^{-1}) \} \\ &\quad \{ \log [100.4 \times 3\,600\,00 \text{ min} \times 5 \text{ K min}^{-1} \times 8.314 \text{ J mol}^{-1} \text{ K}^{-1} / 320\,000 \text{ J mol}^{-1}] + 0.463 \times 49.1532 \} \\ &= \{ 16\,713 \text{ K} \} \{ \log [46\,953] + 22.758 \} \\ &= \{ 16\,713 \text{ K} \} \{ 4.672 + 22.758 \} \\ &= \{ 16\,713 \text{ K} \} \{ 27.430 \} \\ &= 609.3 \text{ K} = 336.1 \text{ }^\circ\text{C} \end{aligned}$$

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X1.3 Example Calculation for the Imprecision in Thermal Index

X1.3.1 Substituting values from X1.1.1.2 and X1.1.3 into Eq 2:

$$\begin{aligned} \sigma TI &= 1.2 \sigma E/E \\ &= 1.2 \times 24\,000 \text{ J/mol} / 320\,000 \text{ J/mol} \\ &= 0.090 \end{aligned}$$

$$\begin{aligned} \sigma TI/TI &= \pm 0.19 \sigma E/E \\ &= 0.19 \times 24\,000 \text{ J/mol}^{-1} / 320\,000 \text{ J/mol}^{-1} \\ &= 0.014 \end{aligned}$$

Expressing as a percent:

$$\begin{aligned} &= 0.014 \times 100\% \\ &= \pm 1.4\% \end{aligned}$$