INTERNATIONAL

Designation: ~~C1057 – 17~~ C1057 – 22

Standard Practice for Determination of Skin Contact Temperature from Heated Surfaces Using a Mathematical Model and Thermesthesiometer[1]

This standard is issued under the fixed designation C1057; 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

1.1 This practice covers a procedure for evaluating the skin contact temperature for heated surfaces. Two complimentary procedures are presented. The first is a purely mathematical approximation that ~~can be~~ is used during design or for worst case evaluation. The second method describes the thermesthesiometer, an instrument that analogues the human sensory mechanism and ~~can be~~is only used ~~only~~ on operating systems.

NOTE 1—Both procedures listed herein are intended for use with Guide C1055. When used in conjunction with that guide, these procedures can determine the burn hazard potential for a heated surface.

1.2 A bibliography of human burn evaluation studies and surface hazard measurement is provided in the References at the end of Guide C1055. Thermesthesiometer and mathematical modeling references are provided in the References at the end of this practice (**1-5**).[2]

1.3 This practice addresses the skin contact temperature determination for passive heated surfaces only. The analysis procedures contained herein are not applicable to chemical, electrical, or other similar hazards that provide a heat generation source at the location of contact.

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~~ safety, health, and ~~health~~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:*[3]

[1] This practice is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.
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[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

[3] 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.

C168 Terminology Relating to Thermal Insulation
C680 Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs
C1055 Guide for Heated System Surface Conditions that Produce Contact Burn Injuries

3. Terminology

3.1 *Definitions*—Terminology C168 shall be considered as applicable to the terms used in this standard.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acceptable contact time*—the limit of time of contact for the heated surface and the exposed skin. Practice has suggested limits of 5 s for industrial processes and up to 60 s for consumer items.

3.2.2 *burns:*

3.2.2.1 *first degree burn*—the reaction to an exposure where the intensity and duration is insufficient to cause complete necrosis of the epidermal layer. The normal response to this level of exposure is dilation of the superficial blood vessels (reddening of the skin).

3.2.2.2 *second degree burn*—the reaction to an exposure where the intensity and duration is sufficient to cause complete necrosis of the epidermis but no significant damage to the dermis. The normal response to this exposure is blistering of the epidermis.

3.2.2.3 *third degree burns*—the reaction to an exposure where significant dermal necrosis occurs. Significant dermal necrosis has been defined in the literature as a 75 % destruction of the dermis thickness. The normal response to this exposure is open sores that leave permanent scar tissue upon healing.

3.2.3 *skin:*

3.2.3.1 *epidermis*—the outermost layer of skin cells. This layer contains no vascular or nerve cells and acts to protect the outer skin layers. The thickness of this layer averages 0.08 mm.

3.2.3.2 *dermis*—the second layer of skin tissue. This layer contains blood vessels and nerve endings. The thickness of this layer is about 2 mm.

3.2.3.3 *necrosis*—localized death of living cells. This is a clinical term that defines when damage to the skin layer has occurred.

3.2.4 *skin contact temperature*—the temperature of the skin at a depth of 0.08 mm reached after contact with a heated surface for a specified time.

3.2.5 *thermal inertia*—a measure of the responsiveness of a material to variations in temperature. This property is also known as thermal effusivity.

3.2.6 *thermesthesiometer*—an electromechanical device developed by L. A. Marzetta at National Institute of Standards and Technology to analogue the touch response of the human skin when it contacts a heated surface. This measurement concept holds U.S. Patent No. 3,878,728 dated April 22, 1975, and was assigned to the USA as represented by the Department of Health and Welfare. No known restriction exists to limit the development of units based upon this principle.

4. Summary of Practice

4.1 This practice provides two procedures for evaluation of the skin contact temperature from heated surfaces. Either of the two methods, a mathematical model and a physical measurement, ~~can be~~ is used depending upon the availability of the system (that is, is it built and operating or is it in the design state) and the operating conditions. The first step in using this practice is to determine which procedure is to be used. Unless the system of interest is operating at design "worst case" conditions, such as high system temperatures and high ambient temperature, the calculational procedure is recommended. On the other hand, if the question is safety at the present conditions, the thermesthesiometer provides a quick measurement with no auxiliary calculations. Paragraphs 4.2 and 4.3 outline the two alternative procedures available.

4.2 *Calculational Procedure, Method A*—First the surface temperature of the insulated system is determined by either a direct measurement, using either thermocouples, thermistors, or infrared noncontact techniques, or by modeling of the system using Practice C680. Once the surface temperature is known, the designer uses the equation set to estimate the maximum epidermal contact temperature for the acceptable contact time. This temperature is a function of surface temperature, time of contact, and composition of both the surface material and substrate. The designer then refers to Guide C1055 to determine the burn hazard potential of the surface.

4.3 *Thermesthesiometer, Method B*—The operator places the calibrated sensor probe face firmly against the heated surface for the acceptable contact time. The device directly reads the contact temperature from the probe. The maximum temperature is used in conjunction with the Guide C1055 to determine the burn hazard potential of the surface.

5. Significance and Use

5.1 The procedures in this practice support the determination of the burn hazard potential for a heated surface. These procedures provide an estimate of the maximum skin contact temperature and must be used in conjunction with Guide C1055 to evaluate the surface hazard potential.

5.2 The two procedures outlined herein are both based upon the same heat transfer principles. Method A uses a mathematical model to predict the contact temperature, while Method B uses a plastic rubber probe having similar heat transfer characteristics to the human finger to "measure" the contact temperature on real systems.

5.3 These procedures serve as an estimate for the skin contact temperatures which might occur for the "average" individual. Unusual conditions of exposure, incorrect design assumptions, subject health conditions, or unforeseen operating conditions ~~may~~ will potentially negate the validity of the estimations.

5.4 These procedures are limited to direct contact exposure only. Conditions of personal exposure to periods of high ambient temperatures, direct flame exposure, or high radiant fluxes ~~may~~ will potentially cause human injury in periods other than determined herein. Evaluation of exposures other than direct contact are beyond the scope of this practice.

5.5 *Cold Surface Exposure*—No consensus criteria exists for the destruction of skin cells by freezing. If, at some future time, such criteria are developed, extrapolation of the techniques presented here will serve as a basis for cold surface exposure evaluation.

6. Method A—Use of the Mathematical Model

6.1 This modeling approach is for use when the system is being designed or, if for some reason, it cannot be operated at design conditions. The model approximates the transient heat flow phenomena of the skin contacting a hot surface using the equation set described by Dussan and Weiner (**1**) and Wu (**5**). The user is required to make certain definitions of system geometry and materials, the system operating conditions, and the allowable time of exposure. After definition of the input values, the equation set yields an estimate of the skin contact temperature needed for the hazard evaluation. The user must realize that as with all mathematical approximations, the estimate is only as good as the input data. Where some input parameter is known only within some range of values, a sensitivity analysis about that range is recommended.

6.2 The first step in estimating the effective skin contact temperature is to identify and record the following information describing the system as input for the model:

6.2.1 *System Description*—Geometry, location, accessibility.

6.2.2 *Present/Design Operating Conditions*—Duty cycle, operating temperatures of equipment.

6.2.3 *System/Surface Data* (as appropriate)—Substrate (insulation) type and thickness, jacket type and thickness, surface properties, such as emissivity and condition, shiny, painted, dirty, corroded.

6.2.4 *Ambient Conditions,* including dry bulb temperature and local wind velocity.

NOTE 2—The design temperatures should be at the worst case (generally high operating and high ambient) conditions. Care should be used in the selection of design conditions since the hazard design conditions are different from the heat loss design conditions.

6.3 Using Practice C680 or a compatible program and the information gathered in 6.2, calculate the maximum operating surface temperature. This temperature is an input to the model for the contact temperature.

6.3.1 Where the system is operating at design conditions, perform a direct measurement ~~can be used~~ to determine the surface temperature. Thermocouples, resistance thermometers, or other means ~~can be used;~~ are options; however, proper application techniques are required for accurate results. Caution must be observed since ~~the surface temperature may be high~~ high surface temperatures are present and the surface ~~could constitute~~ is a potential burn hazard.

6.4 Calculate the expected skin contact temperature versus time history using the procedure below based upon the hot surface temperature, time of contact, and system properties. The development of the equations below is taken from Dussan and Weiner (**1**). A more detailed derivation of the equation set used is included in the papers by Dussan and Weiner (**1**) and Wu (**5**). See Fig. 1.

6.4.1 Calculate the initial parameter constants, using Eq 4-11.

6.4.2 The contact temperature for the skin ~~can now be~~ is determined using Eq 1, Eq 2, and Eq 3 together for the system in question. Note that the solution to this equation is a sum of an infinite series. The solution, however, converges quickly (five or six terms) and ~~can be~~ is easily handled manually or by a small computer.

$$T_c = T_0 + A \sum_{N=0}^{\infty} I^N \, erfc\left(\theta_N\right) + B \sum_{N=0}^{\infty} I^N \, erfc\left(\theta'_N\right) \quad (1)$$

and:

$$\theta_N = \frac{X_1/\sqrt{\alpha_1} + 2 \cdot N \cdot l/\sqrt{\alpha_2}}{2\sqrt{t}} \quad (2)$$

$$\theta'_N = \frac{X_1/\sqrt{\alpha_1} + 2 \cdot (N+1) \cdot l/\sqrt{\alpha_2}}{2\sqrt{t}} \quad (3)$$

$$I = \frac{(P_2 - P_3)\cdot(P_2 - P_1)}{(P_2 + P_3)\cdot(P_2 + P_1)} \quad (4)$$

$$A = \frac{(T_i - T_0)\cdot P_2}{P_2 + P_1} \quad (5)$$

$$B = \frac{(T_i - T_0)\cdot(P_3 - P_2)\cdot P_2}{(P_2 + P_3)\cdot(P_2 + P_1)} \quad (6)$$

$$P_1 = (\rho_1 \cdot C_1 \cdot K_1)^{1/2} \quad (7)$$

$$P_2 = (\rho_2 \cdot C_2 \cdot K_2)^{1/2} \quad (8)$$

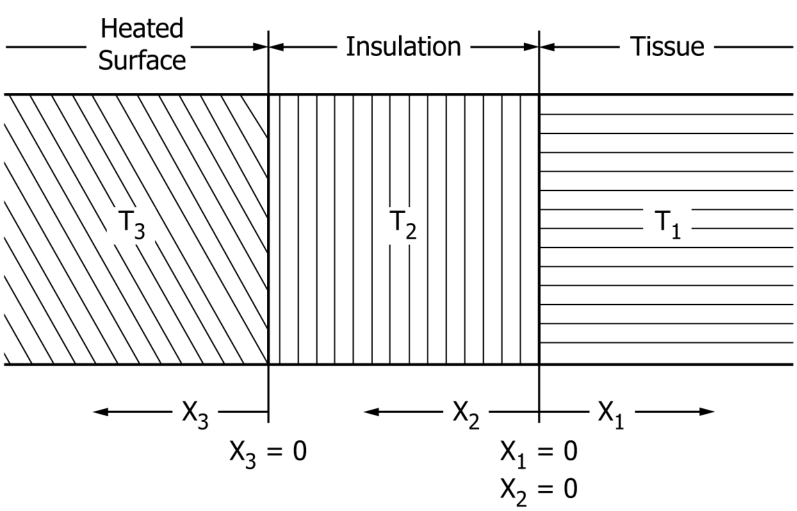

FIG. 1 Schematic of Heat Transfer Model

$$P_3 = (\rho_3 \cdot C_3 \cdot K_3)^{1/2} \quad (9)$$

$$\alpha_1 = K_1/\rho_1 \cdot C_1 \quad (10)$$

$$\alpha_2 = K_2/\rho_2 \cdot C_2 \quad (11)$$

where:

T_0 = initial tissue temperature, °C,
N = integral constant, $1 > \infty$,
X_1 = depth of tissue of interest, normally 8.0×10^{-5} m,
α_i = thermal diffusivity of layer i, m^2/s,
l = layer thickness of jacket material, m,
P = layer thermal inertia;

$$W \cdot m^{-2} \cdot K^{-1} \cdot \sqrt{s},$$

t = time of contact, s,
T_i = initial hot surface temperature, °C,
T_c = contact skin temperature at depth X and at time (t) after contact, °C,
$erfc(\theta)$ = complementary error function (a mathematical function),
ρ_i = density of material i, kg/m^3,
K_i = conductivity of material i, W/m · K, and
C_i = specific heat of material i, J/kg · K.

6.4.3 To obtain the skin contact temperature versus contact time history, repeat the calculation at one second intervals for times up to the maximum contact time exposure expected.

6.4.4 The maximum contact temperature used in the analysis of burn hazard (Guide C1055) is the maximum contact temperature calculated for the contact period in step 6.4.3.

6.5 *Typical Input Data*—Table 1 contains typical values for the commonly used insulation and jacketing materials. Skin properties are also included. ~~Nonstandard~~ It is possible to substitute nonstandard insulations or jacket material properties ~~may be substituted~~ for the table values in the calculation if they are known. Table 2 contains calculated values of Thermal Inertia and Thermal Diffusivity for the 25 materials listed in Table 1 using Eq. 7 and Eq. 10 respectively.

TABLE 1 Typical Properties for 25 Materials at 23°C

Code	Material	Density, kg/m^3	Specific Heat, J/kg · K	Conductivity, W/m · K
1	steel	7800	460	45.2
2	aluminum	2700	960	154.8
3	brass	8900	380	85.4
4	borosilicate glass	2250	840	1.13
5	porcelain	2200	840	1.21
6	concrete	2470	920	2.43
7	brick	1700	840	0.63
8	stone	2300	840	0.92
9	plastics	1280	1550	0.25
10	phenolics	1250	1380	0.042
11	nylons	1110	2090	0.209
12	ABS resins	1040	1510	0.17
13	wood	660	1720	0.13
14	paper	600	2810	0.084
15	human tissue	900	4600	0.544
16	water	1000	4190	0.602
17	cork	130	2010	0.042
18	mineral wool	190	1000	0.059
19	cal silicate	240	1090	0.067
20	foam glass	130	2010	0.071
21	organic foam	50	1050	0.021
22	glass cloth	400	630	0.084
23	fiberglas-LD	100	1000	0.046
24	TFE-fluorocarbon	2150	1050	0.243
25	masonite	1000	1670	0.173

TABLE 2 Calculated Physical Properties for 25 Materials at 23°C

Code	Material	Thermal Diffusivity, $m^2/s \times 10^{-6}$	Thermal Inertia or Thermal Effusivity, $W/m^2 \cdot K \cdot s^{1/2} \times 10^4$
1	Steel	12.6	1.27
2	aluminum	59.7	2.00
3	brass	25.3	1.70
4	borosilicate glass	0.60	0.15
5	porcelain	0.65	0.15
6	concrete	1.07	0.23
7	brick	0.44	0.095
8	stone	0.48	0.13
9	plastics	0.13	0.070
10	phenolics	0.024	0.027
11	nylons	0.090	0.070
12	ABS resins	0.11	0.052
13	wood	0.12	0.038
14	paper	0.050	0.038
15	human tissue	0.13	0.15
16	water	0.14	0.16
17	cork	0.16	0.010
18	mineral wool	0.31	0.011
19	cal silicate	0.26	0.013
20	foam glass	0.72	0.0084
21	organic foam	0.40	0.0033
22	glass cloth	0.33	0.015
23	fiberglas-LD	0.46	0.0068
24	TFE-fluorocarbon	0.11	0.074
25	masonite	0.10	0.054

NOTE 3—Eq 1-11 work with any system of consistent units.

6.6 *Example Calculation*—Using the equations listed in 6.4 and the following input data parameters, the following results were obtained for a simulated burn condition.

6.6.1 *Problem*—Assume a heated system is to be insulated with light density fibrous glass. Jacketing material choices available include: (*1*) aluminum at 0.4 mm thickness and (*2*) glass cloth at 1.0 mm thickness. Also assume that the skin depth of interest is 0.008 cm and the initial skin temperature is 33°C. The question is: What would be the maximum expected contact skin temperature for each jacket material at the desired depth for an exposure of 10 s, if the operating jacket surface temperature is 150°C?

6.6.2 *Result*—In 10 s of exposure the equations above predict a skin temperature at 0.008 cm of approximately 50.2°C for the aluminum jacket and approximately 40.3°C for the glass cloth jacket. See Fig. 2 for the time/temperature histories.

7. Method B—Use of the Thermethesiometer

7.1 The thermesthesiometer approach is for use where the system is operating at the desired design conditions or when evaluation of an existing condition is desired. The thermesthesiometer provides an electrical analogue of the finger's thermal response when placed against a heated surface. ~~Since the use of this device requires some technique, the user should have some experience on known systems as practice before examining unknown surfaces.~~ Experience on known systems as practice before examining unknown surfaces is beneficial since the use of this device requires some technique. Repeating a procedure similar to the calibration on other surface geometries is one method of obtaining this needed training.

7.2 The initial step in the measurement of the effective skin contact temperature using the thermesthesiometer is to identify and record the following information describing the system to be analyzed:

7.2.1 *System Description*—Geometry, location, accessibility.

7.2.2 *Present Operational Conditions*—Duty cycle, system operating temperatures.

7.2.3 *System or Surface Data* (as appropriate)—Substrate (insulation) type and thickness, jacket type and thickness, surface condition, that is shiny, painted, dirty, corroded.

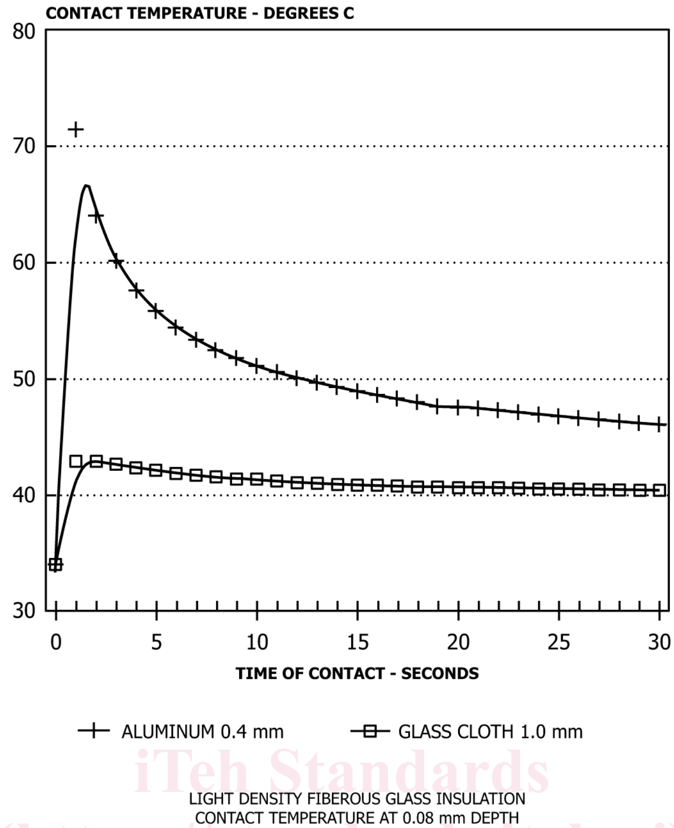

FIG. 2 Time-Contact Temperature History Heated Insulated Surface at 150°C Jacket Material Effects

7.3 Next, measure and record the ambient conditions. This includes:

7.3.1 Dry bulb temperature of air,

7.3.2 Wet bulb temperature of air or relative humidity, and

7.3.3 Localized wind velocity.

7.4 After the system and ambient conditions are defined, locate on the surface several spots that will be measured with the probe. In cases of some geometries, ~~points should be distributed~~ distribute measurement points over the surface to get representative areas. ~~Where~~ Special consideration is necessary where known variations exist in a ~~system, those points should be considered; for~~ system. For example, for a pipe, location ~~selection should~~ selections include: top, sides, and bottom. Mark each point using a marking tool suitable for the surface by circling each point with a large zero. The test will be conducted at the center of each mark. Record on the data sheet the location of the points selected.

NOTE 4—Care should be observed when using the probe on curved surfaces. Surfaces having a diameter less than three times the probe diameter should not be measured.

7.5 Precondition the thermesthesiometer probe and readout by turning on the electronics and waiting at least 30 min for warm-up.

NOTE 5—Individual instructions will be different for each model used in the field. Therefore, consult the unit's operating instructions for the correct warm-up, calibration, and operating procedures.

7.6 Upon warm-up, adjust the probe temperature control until the readout reads 305 ± 2 K. Hold at that condition for five more minutes to ensure equilibrium.