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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Determination of Skin Contact Temperature from Heated Surfaces Using A Mathematical Model and Thermesthesiometer¹

This standard is issued under the fixed designation C 1057; 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.

^{ε1} NOTE—Keywords were added editorially in July 1998.

1. Scope

1.1 This practice establishes 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 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 used only on operating systems.

NOTE 1—Both procedures listed herein are intended for use with Guide C 1055. When used in conjunction with that guide, these procedures can determine the burn hazard potential for a surface.

1.2 A bibliography of human burn evaluation studies and surface hazard measurement is provided in the References at the end of Guide C 1055. Thermesthesiometer and mathematical modeling references are provided in the References at the end of this standard (1-5).²

1.3 *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.*

2. Referenced Documents

2.1 ASTM Standards:

- C 680 Practice for Determination of Heat Gain or Loss and the Surface Temperature of Insulated Pipe and Equipment Systems by Use of a Computer Program³
- C 1055 Guide for Heated System Surface Conditions That Produce Contact Burn Injuries³

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

¹ This practice is under the jurisdiction of ASTM Committee C-16 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 *Annual Book of ASTM Standards*, Vol 04.06.

3.1.1 *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.

3.1.2 *burns*:

3.1.2.1 *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).

3.1.2.2 *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.

3.1.2.3 *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.

3.1.3 *skin*:

3.1.3.1 *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.

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

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

3.1.4 *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.

3.1.5 *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 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. Sections 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 C 680. 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 C 1055 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 C 1055 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 C 1055 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 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 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 (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 C 680 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, direct measurement can be used to determine the surface temperature. Thermocouples, resistance thermometers, or other means can be used; however, proper application techniques are required for accurate results. Caution must be observed since the surface temperature may be high and the surface could constitute a 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 (1). A more detailed derivation of the equation set used is included in the papers by Dussan (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 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

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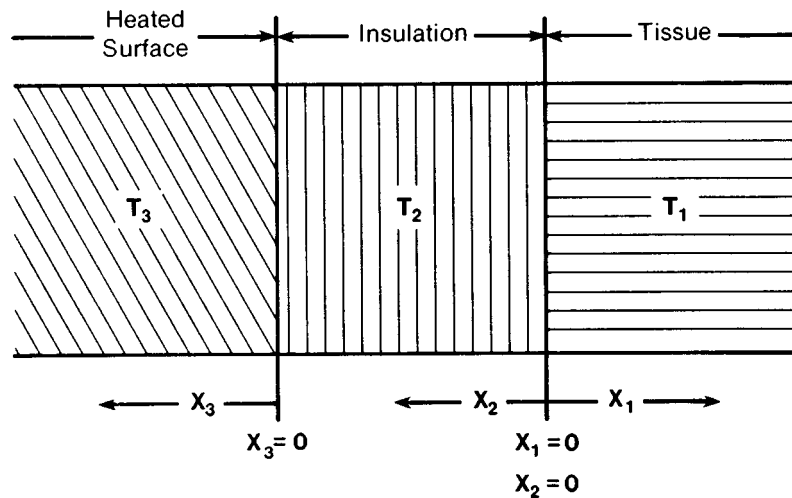


FIG. 1 Schematic of Heat Transfer Model

(five or six terms) and can be easily handled manually or by a small computer.

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

and:

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

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

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

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

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

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

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

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

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

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

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, K,
- T_c = contact skin temperature at depth X and at time (t) after contact, K,
- $\operatorname{erfc}(\theta)$ = complementary error function (a mathematical function),
- ρ_i = density of material i , kg/m^3 ,
- K_i = conductivity of material i , $W/m \cdot K$, and

C_i = specific heat of material i , $J/kg \cdot K$.

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 C 1055) 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 insulations or jacket material properties may be substituted for the table values in the calculation if they are known.

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

TABLE 1 Typical Properties (23°C)

Code	Material	Density, $kg/m^3 \cdot 10^3$	Specific Heat, $J/kg \cdot K \cdot 10^{-3}$	Conductivity, $W/m \cdot K$
1	steel	7.80	0.46	45.200
2	aluminum	2.70	0.96	154.800
3	brass	8.90	0.38	85.400
4	borosilicate glass	2.25	0.84	1.130
5	porcelain	2.20	0.84	1.210
6	concrete	2.47	0.92	2.430
7	brick	1.70	0.84	0.630
8	stone	2.30	0.84	0.920
9	plastics	1.28	1.55	0.250
10	phenolics	1.25	1.38	0.042
11	nylons	1.11	2.09	0.209
12	ABS resins	1.04	1.51	0.170
13	wood	0.66	1.72	0.130
14	paper	0.60	2.81	0.084
15	human tissue	0.90	4.60	0.544
16	water	1.00	4.19	0.602
17	cork	0.13	2.01	0.042
18	mineral wool	0.19	1.00	0.059
19	cal silicate	0.24	1.09	0.067
20	foam glass	0.13	0.76	0.071
21	organic foam	0.05	1.05	0.021
22	glass cloth	0.40	0.63	0.084
23	fiberglass-LD	0.10	1.00	0.046
24	TFE-fluorocarbon	2.15	1.05	0.243
25	masonite	1.00	1.67	0.173