

CONTACT BETWEEN HUMAN SKIN AND HOT SURFACES
EQUILIBRIUM CONTACT TEMPERATURE (T_{ceq})

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INTRODUCTION

Contact between human skin and a hot surface can cause damage to the skin in the form of burns. These can range in severity from erythema (redness) to superficial partial thickness and full thickness burns. In the design and assessment of products and workplaces it would be useful to identify surface temperatures below which no burn would occur and above which a burn would occur. This may help in determining whether a product could be considered safe, for example. These data however are difficult to obtain. It is unethical in experiments, to expose people to a range of temperatures some of which will burn their skin.

An 'ideal' solution would be to develop a mathematical model to 'predict' the reaction of human skin. A problem however is that in practice there are often many factors the effects of which are not known. For example, the effects of pressure or of the surface condition of skin and surface. Although simple models are imperfect, empirical data is scarce and mostly based on the reaction of pig skin, (e.g. Henriques and Moritz 1947) or of standard measuring instruments (Sickman, 1990). Practical application does not usually require perfection but benefits from standardisation of method. A simple model for predicting skin reaction would therefore be of great practical utility.

A Simple Model that 'Doesn't Quite Work'!

A simple model of heat flow between human skin and a solid surface is to represent the skin and surface as two semi-infinite slabs of material. When the two surfaces come into contact, heat flows from the hotter slab to the cooler slab until equilibrium is achieved. However at the interface between the slabs the temperature, called contact temperature, is achieved instantaneously and does not vary. The rate of heat flow and hence when equilibrium will be reached and also the contact temperature will depend upon the properties of the two materials. Ray (1984) cites Van De Held (1939) and provides derivation of a simple model from Fourier's law (see also McIntyre, 1980).

$$T_c = \frac{b_s T_s + b_h T_h}{b_s + b_h} \quad (1)$$

where: T_c = Contact temperature, °C; T_s = Skin surface temperature, °C;

T_h = Temperature of the hot surface, °C; b_s = Thermal penetration coefficient of the skin, $J S^{-1/2} m^{-2} K^{-1}$;

b_h = Thermal penetration coefficient of the hot surface, $J S^{-1/2} m^{-2} K^{-1}$

Where thermal penetration coefficient $b = \sqrt{k \rho c} J S^{-1/2} m^{-2} K^{-1}$ (k = thermal conductivity, ρ = density, c = specific heat capacity).

The utility of the model is that contact temperature can be calculated from the thermal properties of skin and material.

Table 1 Thermal Penetration Coefficients ($b = \sqrt{k \rho c} J S^{-1/2} m^{-2} K^{-1}$)

Human Skin (vasoconstricted)	929-1138
Human Skin (vasodilated)	1314-1971
Aluminium	22265
Iron and Steel	12568
Glass	1288
Concrete	1271-1682
Pine wood	365-519

Consider a short contact between human skin (assume $b = 1000 \text{ JS}^{-1/2} \text{ m}^{-2} \text{ K}^{-1}$) and aluminium ($b = 22,265 \text{ JS}^{-1/2} \text{ m}^{-2} \text{ K}^{-1}$). Assume also a **skin** temperature of 33°C and surface temperature of 80°C.

Then from (1):

$$T_c = \frac{(1000 \times 33) + (22265 \times 80)}{23,265} = 78.0^\circ\text{C}$$

A contact temperature of 78.0°C is likely to produce a partial thickness burn. A problem with the simple model presented is that it is over simplistic. In practice contact will not be perfect and skin condition will be important. This has led to the model being rejected. However such a model can have great practical value if corrections can be made to avoid its unrealistic assumptions.

Equivalent Contact Temperature (T_{ceq})

Equivalent contact temperature (T_{ceq}) is defined as "the temperature between two semi-infinite slabs of material in perfect contact, one slab of hot material and the other of human skin, that would produce equivalent effect on human skin as the actual contact between human skin and the hot surface".

Equivalent contact temperature (T_{ceq}) is given by

$$T_{ceq} = T_c - (T_c - T_{cc}) e^{-(bc/bs)t} \quad (2)$$

- Where
- T_c = Contact temperature from (1) above using a best estimate of skin condition (e.g. vasodilated, 36 or 33°C, vasoconstricted, 30°C).
 - T_{cc} = Contact temperature if the solid surface were made entirely of a coating on the skin (e.g. sweat, grease etc) and corrected for level of contact with a Weighting factor (minimum = 0.2, low = 0.4, medium = 0.6, high = 0.8, maximum = 1.0).
 - b_c = Thermal penetration coefficient of the coating on the skin and corrected for the level of contact as for T_{cc} .
 - t = Contact time in seconds.

Practical Example

Suppose the skin of a machine operator contacts bare steel at 70°C for about 1 second. The skin is vasodilated and sweaty and contact is light.

i) From Table 1 and equation (1) $T_c = \frac{12568.70 + 1500.36}{12568 + 1500} = 66.4^\circ\text{C}$

ii) b for sweat (e.g. water at 60°C) is $1636 \text{ Jm}^{-2} \text{ s}^{-1/2} \text{ K}^{-1}$

iii) Weighting factor for low level of contact = 0.4 $b_c = 0.4 \times 1636 = 654 \text{ Jm}^{-2} \text{ s}^{-1/2} \text{ K}^{-1}$

iv) $T_{cc} = \frac{554.4 \cdot 70 + 1500 \cdot 36}{654.4 + 1500} = 46.3^\circ\text{C}$

v) $T_{ceq} = T_c - (T_c - T_{cc}) e^{-(bc/bs)t} = 66.4 - (66.4 - 46.3) e^{-(654.4/1500) \cdot 1} = 53.4^\circ\text{C}$

A T_{ceq} value of 53.4°C is then compared with temperature values for skin damage.

References

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