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Finite Element Modeling of Bio-Heat Transfer Through Human Tissues

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ABSTRACT :

This paper discusses the extent of burn injuries when a hot cast iron surface at 1000.15 K releases radiation which meets human skin at 5mm. With the help of simulation data in the COMSOL Multiphysics and implementing the bio-heat transfer model, our analysis will examine the distribution of temperature that affects the skin and correspondingly, the intensity of burns. The experiment dwells on the effects of radiation in the hot cast iron and contrasts the concentration of the heat at the epidermis, dermis and subcutaneous skin. The findings give perspective on the severity of burns at any point in time and how radiation is the key player in thermal injury.

Keywords: Radiation burns, bio-heat transfer, skin tissue, temperature distribution, burn intensity, cast iron

Introduction

Radiation burns are one of the major causes of morbidity attributed to thermal injuries [1]. Contact burns have already been discussed thoroughly, but the influence of the radiant heat, especially when it is high, is also vital to safety and treatment plans. Here we investigate radiation effects of burns due to a cast iron surface of 1000.15 K temperature that will be applied to a 5mm distance of human skin [2].

Methodology

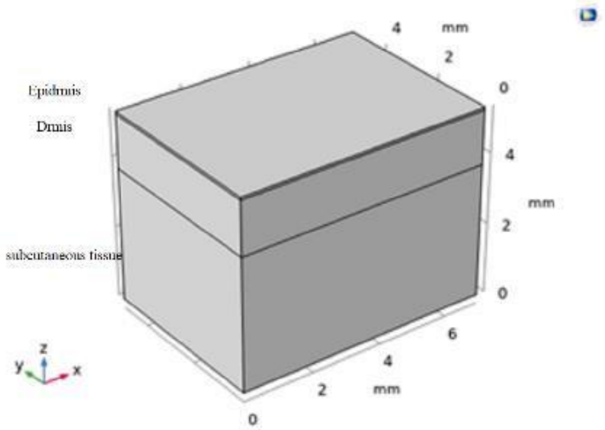
1.1. Bio-Heat Transfer Equation

We use the Penne bio-heat equation, stating changes of the volume of the heat in the structure of biological tissues under various thermal conditions [3]. The penne equation is as under

$$\rho c_p\, \partial T/\partial t = \nabla \cdot (k\nabla T) + \rho_b \omega_b c_b (T_b - T) + Q_{met} + Q$$

1.2. Skin Model and Simulation Setup

The human skin model comprises of three layers epidermis, dermis, and subcutaneous tissue (0.075, 1.5 and 3.75mm respectively). In this work, our attention is paid to the radiation heat source.



Each layer has distinct material properties, including thermal conductivity, specific heat, density and Blood Perfusion Rate. These properties are provided in Table 1.

Skin Layer	Thermal Conductivity ($\frac{W}{m}K$)	Specific Heat ($\frac{W}{Kg}K$)	Density ($\frac{Kg}{m3}$)	Blood Perfusion Rate ($\frac{mL}{s}mL$)
Epidermis	0.21	3598	1200	0
Dermis	0.37	3222	1000	0.00125
Subcutaneous Tissue	0.16	2760	1000	0.00125

1.3. Simulation Setup

In the COMSOL Multiphysics [4], we model the process of heat transfer between the surface of cast iron and the skin. A temperature of 1000.15 K is attributed to the cast iron and radiation intensity will be determined using Stefan-Boltzmann law.

- Case 1 (Radiation by Cast Iron): The only means of heat transfer by radiation, with a constant temperature boundary condition of 1000.15 K provided at the cast iron surface.
- The bottom side of skin is set at 310.15 K temperature and top side of skin under below equation, remaing all sides are thermally constant.

$$Q_{obj} = [A_{obj}\varepsilon_{obj}(\sigma T_{obj}^4 - J_o)]/(1 - \epsilon_{obj})$$

1.4. Calculation Burn Severity:

Burn severity is determined depending on the damage index using the burn integral equation by Henrique to aid in the classification of burns into its degree.
Bio-Heat Transfer Equation:

$$\Omega = \int_0^t Pe^{-\Delta E/RT(t)}\, dt$$

whereby ΔE represents an energy activation, P is the Avant Garde factor, R is the molar gas constant. Based on the damage index, the burns are classified as first, second and third-degree burns based on Ω value.

Results and Discussion

1.5. Temperature Distribution

Heat percentage within the layers of the skin is computed over an interval of time. Since the cast iron radiates the heat, the layers of the skin have varied temperature increase rates. The findings show that the epidermis receives heat mainly, and compared to the lower layers, the changes in temperature rise are rapid.

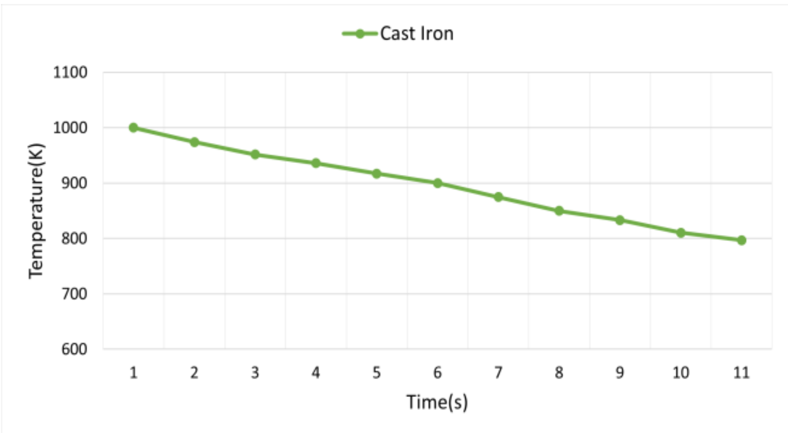


Figure 1: The distribution of temperature that occurs in the skin layers at 20 seconds.

1.6. Analysis of the burn intensity

The calculated temperatures of each of the skin layers are used in the assessment of the burn severity. Burn severity also demonstrates that dermis enters the 2nd degree of burns threshold in a matter of 10 seconds, whereas the dermis and subcutaneous layers are involved to a smaller extent.

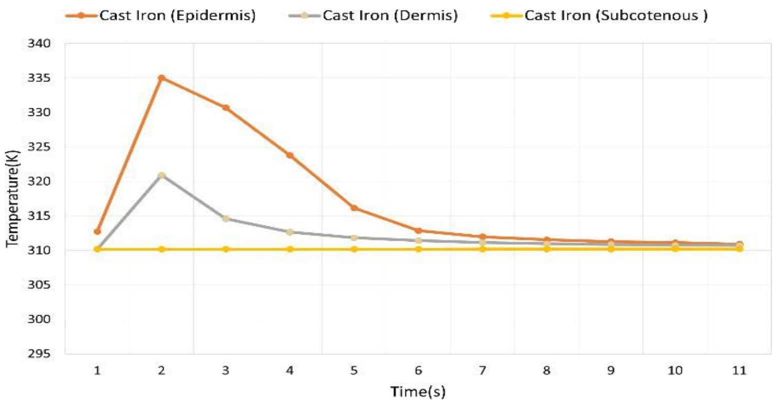


Figure 2: Temperature versus time on epidermis, dermis and subcutaneous levels.

1.7. Burn Severity

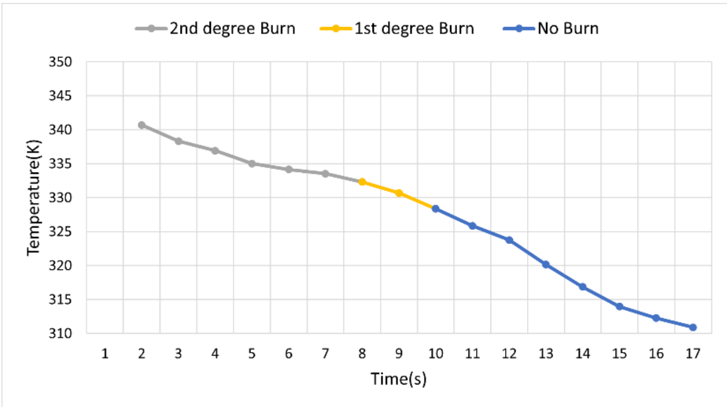


Figure 3: Burn severity over the epidermis, the dermis, and subcutaneous tissue.

Conclusions

According to the study, it is true that when exposed to radiant energy of an object like a 1000.15 K cast iron, a very high temperature, one would experience severe burns in a short time, particularly to the epidermis. The information provided in the study may be introduced to strengthen the safety conditions and protection against thermal radiation exposure.

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