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Temperature Distribution in Dermal Tissue with Burn Injury

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ABSTRACT: This chapter deals with the study of one dimensional steady state temperature distribution in human skin and subcutaneous tissue with burn injury. It is assumed that the outer surface of the skin is exposed to the hot source resulting pain and burn injury in the skin and subcutaneous tissue. Surrounding atmospheric temperature of the skin is assumed to be equal to hot source temperature. Skin is divided into two layers namely epidermis and dermis. According to biological structure of the region, the rate of blood mass flow, the rate of metabolic heat generation and the tissue thermal conductivity are assumed to be constants in epidermis and subcutaneous tissue but variables in dermis with respect to the position. Arterial blood temperature is taken position dependent. Mathematical model for steady state case is solved with the help of finite element method. Theoretical results are discussed numerically and graphically.

Keywords: Finite Element Method (FEM) Rayleigh–Ritz Finite Element Method Variational Finite Element Method (VFEM).

INTRODUCTION

The biological materials are mostly composite. The human body is not an exception. More than 70% of the human body is composed of fluids. The purpose of these fluids is to help several physiological activities including the thermoregulation process of human body irrespective of change of environmental temperatures and through which the body goesthrough during daily activates.

Animal of Human Skin is one of the best composite material skin of all living being is not only a protective device of body but its application in the process of body thermo regulation plays an important role in physiological functions. The process of thermo regulation in all homoiotherms or warm blooded animals resembles and can be analyzed under a common study. The human system is most sophisticated in this regard and will be useful to understand all other systems whatsoever, thedeep body tissue temperature (body core temperature) is different in different animals, while it remains almost exactly constant within ±1ºF (or ± 0.6ºC) of human body despite to the core temperature rises and falls with the temperatures, but the skin temperature, in contrast to the core temperature rises and falls with the temperature of the surroundings. Thus, any irregularity in the temperature distribution in dermal layers due to abnormal environment causes the disturbances in thermo regulation and hence has clinical and theoretical importance. Therefore, the study of heat flow in human skin exposed to abnormal atmospheric temperatures, which can cause thermal injuries in dermal parts, is useful (Ashrae, 1977).

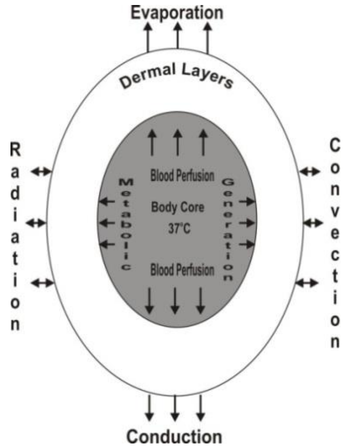

Fig. 1. Heat Exchange Between Human Body at Rest and the Atmosphere.

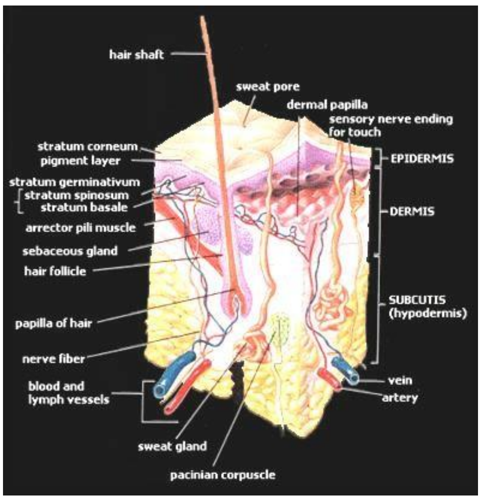

Fig. 2. Human Dermal with Major Constituents.

The Burn Injury. When human body is exposed continuously to an atmosphere at 45°C or higher temperatures the outer parts are damaged and burn injury is caused. Burns constitute the most complex form of tissue injury. The depth of the injury depends on the intensity and duration of heat application and involved tissue conductivity. Injuries are also observed in patients who have been exposed or direct contact with hot metal, toxic chemicals or high voltage electric current. Fire accidents are also common cause of burn injury. A principal difference between burn injury and chemical injury is the length of time during which tissue damage continues, since the chemical agent cause progressive damage until inactivated by reaction with tissue, while burn injury ceases shortlyafter removal of heat source (Takata *et al.,* 1977).

In electrical injury, the damage of skin is very minimum in comparison to burn and chemical injury. In electrical injury, the magnitude of the injury is directly related to the amount of current passing through tissue between the point of contact and exit site. The magnitude of current passing through various organs is indirectly related to the resistance of the tissue. Nerve, blood and muscle offer the least resistance to electric current and thus sustain the maximum amount of tissue damage.

Classification of Burns. On the basis of the damages suffered by the tissue due to any of the above causes, the burs are classified as of first, second and third degree.

(i) First degree burns: First degree burns are characterized by simple ethema of the skin, with only microscopic destruction of superficial layers of the epidermis. A mild sun burns is bestexample of a first degree bur injury. In this injury, water barriers of the skin are not disturbed.

(ii) Second degree burns: Second degree burns extend through the epidermis into the dermis. By definition viable epithelial elements from which epithelial regeneration can occur are attained second degree burn injury.

(iii) Third degree burns: Third degree burns are characterized by total irreversible destruction of all the skin including dermal appendages and epithelial elements.

Second and third degree burns may be summated in the estimation of total body surface burn injury.

The length and width of the burns wound is expressed as a percentage ofthe total body surface area displaying either second or third degree burns. The extent of the body surface involved is most commonly estimated by the rule of niches.

The major anatomic portions of the adults may be divided into multiple of nine percent of the body surface area. The portion of each of these areas with second or third degree burns is estimated and summation of these estimates represents the percentage of the total body surface area of burns.

The local outpouring of the third degree is the burned area resulting in a remarkable concentration of the blood and this leads in turn to circulatory failure and oxygen starvation of these tissues.

Body Fluid Alterations Following Burn Injury. The burn injuries result in evaporative loss is measured in terms of vapor pressure measured at the surface of the skin of the burns wound. Partial thickness burns around and donor sites loss water at intermediate rate. The evaporative loss can amount to as much as 6 to 8 litres/day in an extensive full thickness thermal injury (Ross and Diller 1976).

Metabolic Changes Due To Burn Injuries. The metabolic stress resulting from burn injury by Saxena (1995) is related to burn size. With metabolic rate rising in a curvilinear fashion, metabolic rate also varies with post-injury time and oxygen consumption which may be near normal during resuscitation. Rises and peaks during the flow phase of injury and decreases in curvilinear manner to return to predicted basal levels when hearing or resolution of the infection is achieved.

Increased water loss from the burns would result in surface cooling and may simulate metabolic heat production so as to generate more heat in order to maintain body temperature (Arya & Saxena 1981). Since increased oxygen consumption and insensible water loss are both correlated with burn size, hyper metabolism has previously been related to surface cooling, secondary to increased evaporative water loss from the burn wound.

Infection Resulting From Burn Injuries. All burns would be considered to be infected to some extent. It appears that the burns wound passes through three successive stages namely sterile, contaminated and infected.

Damage Following Burn Injury. The damage to tissue subject to excessive heating depends on intensity and duration of heat application. Damage as a result of hear rarely occurs below 45ºC de-nutrition to protein elements of the cell becomes apparent. In temperature ranges between 45ºC to 50ºC gradation of cell injury may occur and above 50ºC de-nutrition of protein elements of the cell becomes apparent. In temperature range between 44ºC to 51ºC at the surface**, the rate of cellular destruction double with each degree rise in temperature and only limited exposure.**

The Damage Estimation. The mathematical estimation of burn injury can be estimated with the help of damage function **Ω** by Vinod *et al.* (2009) given below:

$$\Omega(x,t) = A\int_0^t e^{\left(-\frac{\Delta E}{R u}\right)}\,dt \qquad (1)$$

$u(x,t) =$ Tissue temperature

R= Gas constant

A= Frequency factor

$\Delta E =$ Activation Energy

The degree of burn depending on damage function is

First degree burn **Ω** = 0.53

Second degree burn **Ω** = 1.0

Third degree burn **Ω** = 10^4

These experimental values of Ω for first and second degree burns were defined by Moritz and Henrique (1947).

Mathematical Formulation. The partial differential equation coupled with boundary conditions, written in one-dimensional steady – state case and compared with the Euler-Lagrange's equation is transformed into the following equivalent form Saxena *et al.* (2005)

$$I=\frac{1}{2}\int_0^l\left[K\left(\frac{du}{dx}\right)^2+M(u_b-u)^2-2Su\right]dx$$
$$+\frac{h}{2}(u-u_a)^2+LEu \quad (2)$$

Now the entire thickness of SST is divided into thirteen unequal parts termed as 'elements'. This division is presumably based on physiological relevance. To start with, Epidermis which has two distinct layers namely, Stratum Corneum and Stratum Germinativum; is covered by four elements. Each layer consists of two elements. Such type of division provides flexibility in assigning suitable and independent values to quantities like thermal conductivity, rbmf, rmhg etc. The very idea of applying **Finite Element Method** to this problem is based on the same fact. Dermis and sub-dermal part are also assumed to have four and five subdivisions (elements) respectively (Diller and Pearce 1999).

Value u_r (r = 0, 1, 2,………, 13) are assigned to u at the interfaces at distances l_r (r = 0, 1, 2,…………, 13) from the outer skin surface. In terms of geometrical representation u_1, u_2,……u_{12} are internal points on the temperature profile curve with end points u_0 and u_{13} (37°C) and each branch of the curve between two consecutive points can be represented by part of the polygon obtained by joining them by straight lines. Let $u^{(i)}$ (i = 1, 2,……, 13) represents the linear values of u (x) for l_i-1 < x < l_i that is

$$u^{(i)}=\frac{l_i\,u_{i-1}-l_{i-1}\,u_i}{l_i-l_{i-1}}+\frac{u_i-u_{i-1}}{l_i-l_{i-1}}x,$$

Evidently $u^{(i)}\to u_i$ as $x\to l_i$; where $l_0=0$

l_2 = a, l_4 = b, l_8 = c and l_{13} = d

Accordingly $I=\sum_{i=1}^{13}I_i$ (3)

Where

$$I_i=\frac{1}{2}\int_{l_{i-1}}^{l_i}\left[K_i\left(\frac{du^{(i)}}{dx}\right)^2+M_i(u_b{}^{(i)}-u^{(i)})^2-2S_iu^{(i)}\right]dx$$
$$+\frac{h}{2}(u^{(i)}-u_a)^2+LEu^{(i)} \quad (4)$$

The expressions outside the integral sign will appear only when i = 1, K_i, M_i, $u_a{}^{(i)}$ and S_i denote functions representing the quantities K, M (= m_bc_b), u_b and S respectively in the i^{th} element. Their element wise assumptions are described below.

As the stratum corneum consists of dead cells, there is no blood flow and no metabolic heat generation in this region. In the adjoining stratum germin ativum also, the blood capillaries are generally absent. However, there is some metabolic activity in this part and it increases gradually along the deeper side towards the dermis. The thermal conductivity is assumed to be constant for the entire epidermal region. Thus, for the first four elements covering epidermis, it is assumed that

$$\left.\begin{array}{l}K_i=K_e\,(\text{constant})\\ M_i=0\end{array}\right]\text{for } i=1(1)4 \quad (5)$$

$$S_i=o \text{ for } i=1,2 \quad (6)$$

$$S_i=s\left(\frac{x-a}{c-a}\right)^{p_e}[1+q_e(u_i-u_{i-1})]\text{ for } i=3,4; \quad (7)$$

s, p_e and q_e are constants and have to be assigned suitable values. i = m (1) n means i = m, m + 1, m + 2,…..n, s and q_e depend on body core temperature and atmospheric temperature while p_e and prescribes mode of variation of rmhg with respect to x. It may be recalled that $l_{i-1}\le x\le l_i$. For the next four elements covering Dermis, the above assumption regarding rmhg with same or different values of constants will still be valid. Here

$$S_i=s\left(\frac{x-a}{c-a}\right)^{p_d}[1+q_d(u_i-u_{i-1})] \quad (8)$$

For i = 5 (1) 8.

The assumptions (7) and (8) regarding S_i are general in nature and the two expressions on the right hand sides are constructed in a view to approximate variation of rmhg in mixed in-vivo tissue regions like SST. These two functions provide different space wise variations to rmhg for different types of layers of cells by choosing suitable values p_e and p_d. By including a term containing u_i and u_{i-1} they also obey important condition that the rmhg is self controlled. The other two quantities q_e and q_d may be assigned values depending on the atmospheric and body core temperatures. Specific values will be given to all the constants later on while obtaining the solution.

The variation of M_i in Dermis in mainly due to difference in population density of blood vessels at different depths and it can be reasonably assumed that

$$M_i=m\left(\frac{x-b}{c-b}\right)^{r_d}\text{ for } i=5(1)8; \quad (9)$$

m and r_d are suitable constants. Also

$$Ki=K_d\,(\text{constant})\text{ for } i=5(1)8 \quad (10)$$

The sub-dermal tissues (c < x < d) have uniform properties and we can have

$$\left.\begin{array}{l}S_i=s[1+q_s(u_i-u_{i-1})]\\ K_i=K_s\,(\text{constant})\\ M_i=m\end{array}\right] \quad (11)$$

Where q_s, K_s and m are constants.

It is difficult to assign a fixed expression or value to the arterial blood temperature u_b. The small element width may required definite information regarding capillary network in the region to determine this quantity. However, in view of very low blood velocity, it can be taken as average of the temperatures of the adjoining nodes *i.e.*

$$u_b=\frac{1}{2}(u_{i-1}+u_i),\,i=5(1)13 \quad (12)$$

Lastly, linear variations of S_i (for i = 5 (1) 8) and M_i (for i = 5 (1) 8) have been assumed *i.e.*

$$p_e=p_d=r_d=1 \quad (13)$$

and $q_e=q_d=q.$ (14)

The assumptions regarding linear variations of S_i and M_i are reasonably good for human subjects with normal body weights. For the other cases with thin skin layers or abnormal deposition of fat cells a more rigorous mathematical analysis may be required (Saxena and Yadav 1998)

Model Solution

For i = 1

$$I_1 = \frac{1}{2}\int_0^{l_1}\left[K(u^{(1)'})^2 dx + \frac{h}{2}\left(u^{(1)}\right)^2\right]dx + LEu_0 \quad (15)$$

or $$I_1 = F_0(u_1 - u_0)^2 + F_1u_0^2 + F_2u_0 + F_3 \quad (16)$$

For i = 2

$$I_2 = F_4(u_2 - u_1)^2 \quad (17)$$

For i = 3

$$I_3 = \frac{1}{2}\int_{l_2}^{l_3}\left[K_3(u^{(3)'})^2 + M_3\left\{u_b^{(3)} - u^{(3)}\right\}^2 - 2S_3u^{(3)}\right]dx \quad (18)$$

$$I_3 = F_5u_3^2 + F_6u_2^2 + F_7u_2u_3 + F_8u_3 + F_9u_2 \quad (19)$$

Similarly

$$I_4 = F_{10}u_4^2 + F_{11}u_3^2 + F_{12}u_3u_4 + F_{13}u_4 + F_{14}u_3 \quad (20)$$

For i =5 (1) 8

$$I_5 = \frac{1}{2}\int_{l_4}^{l_5}\left[K_5\left(u^{(5)'}\right)^2 + M_5\left\{u_b^{(5)} - u^{(5)}\right\}^2 - 2S_5u^{(5)}\right]dx \quad (21)$$

or

$$I_5 = G_1u_5^2 + G_2u_4^2 + G_3u_5u_4 + G_4u_5 + G_5u_4 \quad (22)$$

$$I_6 = G_6u_6^2 + G_7u_5^2 + G_8u_6u_5 + G_9u_6 + G_{10}u_5 \quad (23)$$

$$I_7 = G_{11}u_7^2 + G_{12}u_6^2 + G_{13}u_7u_6 + G_{14}u_7 + G_{15}u_6 \quad (24)$$

$$I_8 = G_{16}u_8^2 + G_{17}u_7^2 + G_{18}u_8u_7 + G_{19}u_8 + G_{20}u_7 \quad (25)$$

For i = 9 (1) 13

$$I_9 = \frac{1}{2}\int_{l_8}^{l_9}\left[K_9\left(u^{(9)^1}\right)^2 + M_9\left\{u_b^{(9)} - u^{(9)}\right\}^2 - 2S_9u^{(9)}\right]dx \quad (26)$$

$$I_9 = H_1u_9^2 + H_2u_8^2 + H_3u_9u_8 + H_4u_9 + H_5u_8 \quad (27)$$

$$I_{10} = H_6u_{10}^2 + H_7u_9^2 + H_8u_{10}u_9 + H_9u_{10} + H_{10}u_9 \quad (28)$$

$$I_{11} = H_{11}u_{11}^2 + H_{12}u_{10}^2 + H_{13}u_{11}u_{10} + H_{14}u_{11} + H_{15}u_{10} \quad (29)$$

$$I_{12} = H_{16}u_{12}^2 + H_{17}u_{11}^2 + H_{18}u_{12}u_{11} + H_{19}u_{12} + H_{20}u_{11} \quad (30)$$

$$I_{13} = H_{21}u_{13}^2 + H_{22}u_{12}^2 + H_{23}u_{13}u_{12} + H_{24}u_{13} + H_{25}u_{12} \quad (31)$$

Putting these values in equation (3), we get

$$\begin{aligned}
I = {} & F_0(u_1 - u_0)^2 + F_1u_0^2 + F_2u_0 + F_3 + F_4(u_2 - u_1)^2 + \\
& F_5u_3^2 + F_6u_2^2 + F_7u_2u_3 + F_8u_3 + F_9u_2 \\
& + F_{10}u_4^2 + F_{11}u_3^2 + F_{12}u_3u_4 + F_{13}u_4 + F_{14}u_3 \\
& + G_1u_5^2 + G_2u_4^2 + G_3u_5u_4 + G_4u_5 + G_5u_4 \\
& + G_6u_6^2 + G_7u_5^2 + G_8u_6u_5 + G_9u_6 + G_{10}u_5 + \\
& G_{11}u_7^2 + G_{12}u_6^2 + G_{13}u_7u_6 + G_{14}u_7 + G_{15}u_6 \\
& + G_{16}u_8^2 + G_{17}u_7^2 + G_{18}u_8u_7 + G_{19}u_8 + G_{20}u_7 \\
& + H_1u_9^2 + H_2u_8^2 + H_3u_9u_8 + H_4u_9 + H_5u_8 \\
& + H_6u_{10}^2 + H_7u_9^2 + H_8u_{10}u_9 + H_9u_{10} + H_{10}u_9 \\
& + H_{11}u_{11}^2 + H_{12}u_{10}^2 + H_{13}u_{11}u_{10} + H_{14}u_{11} + H_{15}u_{10} \\
& + H_{16}u_{12}^2 + H_{17}u_{11}^2 + H_{18}u_{12}u_{11} + H_{19}u_{12} + H_{20}u_{11} \\
& + H_{21}u_{13}^2 + H_{22}u_{12}^2 + H_{23}u_{13}u_{12} + H_{24}u_{13} + H_{25}u_{12}
\end{aligned}$$

For optimizing I differentiate it with respect to u_0, u_1,………u_{12}

i.e. $\frac{\partial I}{\partial u_i} = 0$ for i = 0 (1) 12

to obtain system of equations

$$(F_1 + F_0)u_0 - F_0u_1 = \frac{-F_2}{2} \quad (32)$$

$$-F_0u_0 + (F_0 + F_4)u_1 - F_4u_2 = 0 \quad (33)$$

$$-2F_4u_1 + 2(F_4 + F_6)u_2 + F_7u_3 = -F_9 \quad (34)$$

$$F_7u_2 + 2(F_5 + F_{11})u_3 + F_{12}u_4 = -F_8 - F_{14} \quad (35)$$

$$F_{12}u_3 + 2(F_{10} + G_2)u_4 + G_3u_5 = -F_{13} - G_5 \quad (36)$$

$$G_3u_4 + 2(G_1 + G_7)u_5 + G_8u_6 = -G_4 - G_{10} \quad (37)$$

$$G_8u_5 + 2(G_6 + G_{12})u_6 + G_{13}u_7 = -G_9 - G_{15} \quad (38)$$

$$G_{13}u_6 + 2(G_{11} + G_{17})u_7 + G_{18}u_8 = -G_{12} - G_{18} \quad (39)$$

$$G_{18}u_7 + 2(G_{16} + H_2)u_8 + H_3u_9 = -G_{20} - H_6 \quad (40)$$

$$H_3u_8 + 2(H_1 + H_7)u_9 + H_8u_{10} = -H_4 - H_{10} \quad (41)$$

$$H_8u_9 + 2(H_6 + H_{12})u_{10} + H_{13}u_{11} = -H_9 - H_{15} \quad (42)$$

$$H_{13}u_{10} + 2(H_{11} + H_{17})u_{11} + H_{18}u_{12} = -H_{14} - H_{20} \quad (43)$$

$$H_{18}u_{11} + 2(H_{16} + H_{22})u_{12} + H_{23}u_{13} = -H_{19} - H_{25} \quad (44)$$

All these equations can be written as matrix form as

$$A\,U = B \quad (45)$$

Where A= Coefficient Matrix

U = [u_0,u_2……..u_{12}]T = Column matrix

B = [b_1, b_2…….b_{13}]T = Column matrix of constants

NUMERICAL RESULTS

The following values of physical and physiological constants have been taken-

K_1= 0.5× 10^{-3} cal/cm s c^0, K_3= 1.0× 10^{-3} cal/cm s c^0

$m_b c_b$=0.525× 10^{-3} cal/cm³ s c^0, S=0.3× 10^{-3} cal/cm s

h= 3× 10^{-3} cal/cm² s c^0, L=579 cal/gm

E=0.16× 10^{-3} gm/cm² s, u_b =37°C

A= 3× 10^{98} / s

$\Delta E = 6.3 \times 10^8$ J/k mol

R= 8.3136× 10^3 J/k mol c^0

Table 1: Values of l_i (i = 0, 1, 2, …… 13) in cm.

	l_0	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}
Set – I	0	0.015	0.03	0.045	0.06	0.11	0.16	0.21	0.26	0.31	0.36	0.41	0.46	0.51
Set – II	0	0.025	0.05	0.075	0.1	0.175	0.25	0.325	0.4	0.5	0.6	0.70	0.8	0.9
Set – III	0	0.05	0.1	0.15	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1

For above sets of SST structure temperature values have been estimated at the nodal points and damage function Ω has been calculated by using the formula (1). The values are listed in the following Tables.

Table 2.

Time t (hours)	Damage Function Ω (0, t)		
	Set I	Set II	Set III
8.0	0.273	0.360	0.471
9.0	0.307	0.405	0.530
10.0	0.341	0.450	0.589
11.0	0.375	0.495	0.648
12.0	0.410	0.540	0.707
13.0	0.444	0.585	0.766
14.0	0.478	0.630	0.825
15.0	0.512	0.675	0.884
16.0	0.546	0.720	0.943
17.0	0.580	0.765	1.002
18.0	0.614	0.810	1.060
19.0	0.649	0.855	1.119
20.0	0.683	0.901	1.178
21.0	0.717	0.946	1.237
22.0	0.751	0.991	1.296
23.0	0.785	1.036	1.355
24.0	0.819	1.081	1.414
25.0	0.853	1.126	1.473

Damage Function for Different Values of Time for Set I, Set II and Set III, When u_a = 80°C and x = 0.0 cm

Table 3.

Timet (minutes)	Damage Function Ω (0, t)		
	Set I	Set II	Set III
30	0.205	0.30	0.445
40	0.237	0.40	0.593
50	0.341	0.499	0.741
60	0.409	0.599	0.889
70	0.478	0.699	1.037
80	0.546	0.799	1.185
90	0.614	0.899	1.334
100	0.682	0.999	1.482
110	0.751	1.099	1.630
120	0.819	1.199	1.778
130	0.887	1.299	1.926
140	0.955	1.398	2.075
150	1.024	1.498	2.223
160	1.092	1.598	2.371
170	1.160	1.698	2.519
180	1.228	1.798	2.667

Damage Function for Different Values of Time for Set I, Set II and Set III, When u_a = 85°C and x = 0.0 cm

Table 4: (where a= l_2).

Time t (Hrs)	Damage Function Ω (a,t) Set III
10	0.385
11	0.423
12	0.462
13	0.500
14	0.539
15	0.577
16	0.616
17	0.654
18	0.693
19	0.731
20	0.770
21	0.808
22	0.847
23	0.885
24	0.923
25	0.943
26	0.981
27	1.020

Damage Function for Different Values of Time for Set III,
When u_a = 85°C and x = 0.15 cm

Table 5.

Time t (Minutes)	Damage Function Ω (0, t)		
	Set I	Set II	Set III
1	0.078	0.127	0.212
2	0.157	0.253	0.424
3	0.235	0.380	0.636
4	0.313	0.507	0.847
5	0.392	0.633	1.059
6	0.470	0.766	1.271
7	0.548	0.887	1.483
8	0.627	1.013	1.695
9	0.705	10140	1.907
10	0.783	1.267	2.118
11	0.862	1.393	2.330
12	0.940	1.520	2.542
13	1.018	1.647	2.754
14	1.097	1.773	2.996
15	1.175	1.900	3.178

Damage Function for Different Values of Time for Set I, Set II and Set III, When u_a = 90ºC and x = 0.0 cm

Table 6: (where a= l_2).

Time t (Minutes)	Damage Function Ω (a, t)		
	Set I	Set II	Set III
120	0.364	0.179	0.493
140	0.425	0.209	0.575
160	0.486	0.238	0.657
180	0.546	0.268	0.739
200	0.607	0.298	0.822
220	0.668	0.328	0.904
240	0.729	0.358	0.986
260	0.789	0.387	1.068
280	0.850	0.417	1.150
300	0.911	0.447	1.232
320	0.971	0.477	1.315
340	1.032	0.507	1.397
360	1.093	0.536	1.479
380	1.153	0.566	1.561
400	1.214	0.596	1.643
420	1.275	0.626	1.725
440	1.336	0.656	1.808
460	1.396	0.685	1.890
480	1.457	0.715	1.972

Damage Function for Different Values of Time for Set I, Set II and Set III, When u_a = 90ºC and x = a cm

CONCLUSIONS

The final results of this thesis are presented in the form of damage function which is calculated by incorporating time dependent local temperatures. These temperatures have been calculated analytically in this chapter for exposure of the body to hot atmosphere. Different thicknesses of skin layers have been assume to cover a variety of in-vivo samples.

The values of damage function indicate variation for the thicknesses of sub-regions; in particular for the deeper parts. These results will prove useful information regarding burn injuries of a particular individual in relation with atmospheric conditions.

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