CHAPTER - 5

DEVELOPMENT OF BURN HAZARD POTENTIAL TESTER (BHPT) AND TESTING METHOD

5.1 INTRODUCTION

There exits wide varieties of test standards used to describe the burning behaviour of various materials; however, these are not applicable to apparels used in India in general and saree in particular. Testing the flammability of a material should include the measurement of various properties such as ignition, flame spread, and heat release etc. Ignition is the initiation of combustion, flame spread is the movement of the flame across the specimen, and heat release refers to the amount of energy released during the combustion process.

Flammability is defined as characteristics of a material pertaining to its relative ease of ignition and ability to sustain combustion.[2] Instruments measuring flammability mostly rely on pass-fail criteria and no simple equipment is available to correlate the thermal characteristics with the burn injury.

This chapter outlines the operation, components and design of the Burn Hazard Potential Tester (BHPT). In addition, it covers sample preparations particularly for saree, prerequisite for testing, testing procedure for analysis of burning behaviour and necessary calculations.

5.2 PRINCIPLE OF OPERATION AND DESIGN

The operating principle of Burn Hazard Potential Tester (BHPT) is based on measurement of incident heat flux released during burning of fabric sample. The tester mainly measures incident heat, released during the burning of the fabric sample. This provides the real fire situation (in-situ condition) where the skin is exposed to the incident heat released during the burning of the fabric.
The BHPT was designed to allow small samples of fabric to be tested for determining their relevant thermal properties. The flammability of a fabric can

be measured in terms of both pre-ignition and post-ignition characteristics such as:

i) Time for ignition
ii) Flame propagation rate
iii) Burning rate
iv) Heat release rate during burning

The test is designed such that individual samples could be tested separately, or combined into assembly. A constant heat flux level is used to ignite the fabric sample. The liquid petroleum gas is used as fuel for the flame to burn the test specimen.

5.3 TESTER CONFIGURATION

Fig. 5.1 shows the schematic diagram of the BHPT which consists of a specimen rack, an ignition medium and three automatic timing devices (T_1, T_2, T_3) and a temperature display tutor (T_4) enclosed in a draft proof ventilated chamber 35 cm high, 36 cm wide and 20 cm deep. The chamber is made up of stainless steel having a door made up of transparent acrylic sheet. There are 12 holes equidistance to each other, each is around 12 mm along the rear of the top closure and ventilation is provided from the base of front door through a slit.

The specimen rack supports the frames in which the specimen holders are mounted. The rack can be rotated from horizontal to vertical by means of a screw. The specimen holder consists of two 50 mm x 150 mm stainless steel frames with clamps mounted along the sides, between which the specimen is fixed. The plates are slotted and loosely pinned for alignment. The two plates cover all but 38 mm of the width of the specimen for its full length. The specimen holder frame is supported on the rack. At the top end of the rack where the specimen ends, a stop cord is stretched from the spool through suitable thread guides provided on the specimen frame and chamber walls and hanged by a dead weight, the stop cord is 40^s cotton sewing thread. The dead weight, attached by means of a clip to the stop cord, on dropping stops a timer T_2. (Fig. 5.2)

A very thin silver plate (3 cm x 1cm) is fixed in plane with the top face of the specimen rack (Fig.5.7). This plate is fixed at the centre of the rack in such a way that the center of the silver plate and centre of the specimen holder coincides. In front of the specimen rack, a rotating micro burner is mounted (Fig.5.2). A timer-operated motor controls the movement of this micro burner and the time for impeachment of flame on to the specimen, Timer T_1 sets the time for impeachment of flame (Fig.5.3). The sensitive fuel control valve regulates the Liquid petroleum gas supply to the micro burner from the cylinder; a manometer

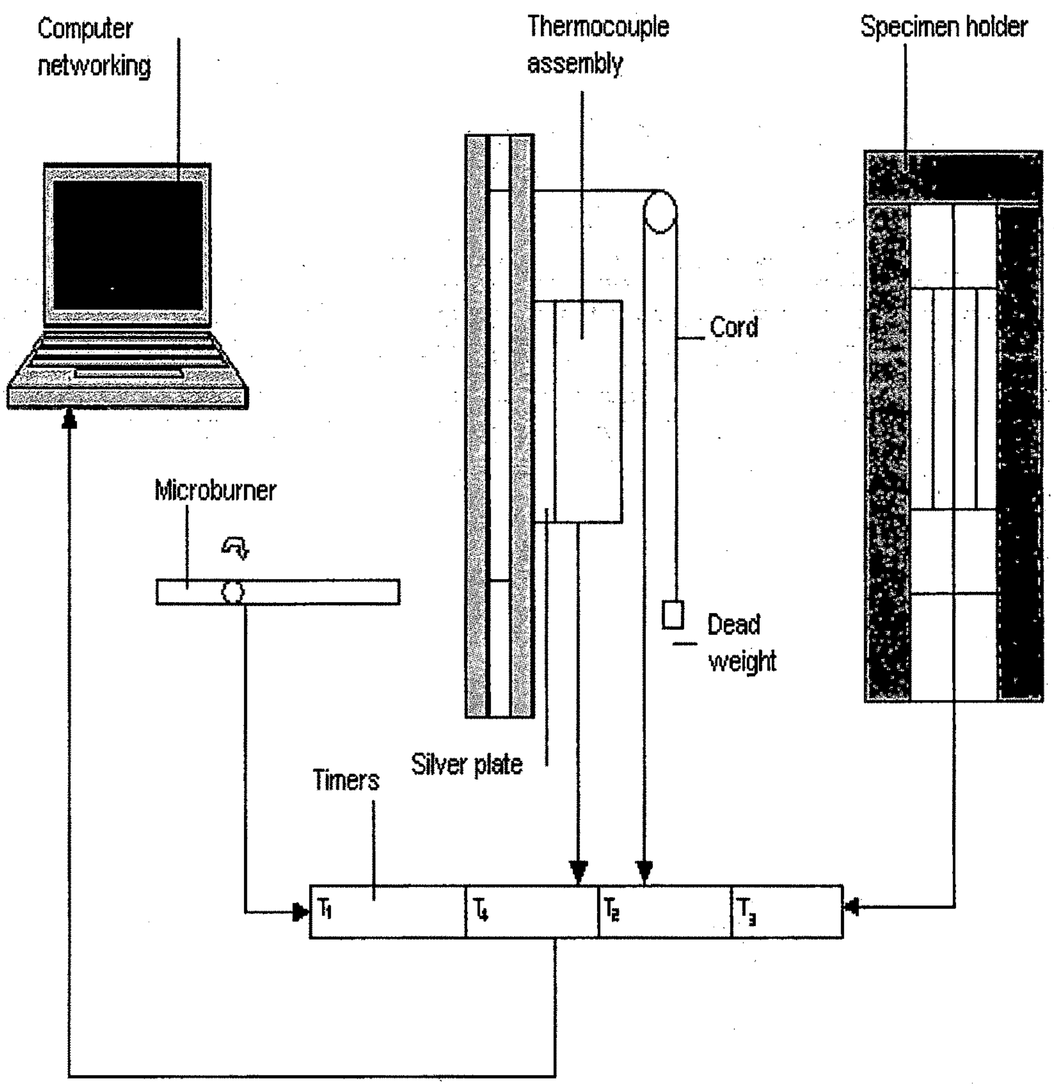

Fig. 5.1 Schematic diagram of Burn Hazard Potential Tester (BHPT)

consists of U shaped glass tube into the gas line to register the gas pressure delivered to the micro burner.

The complete testing process is controlled and monitored by means of timers provided for controlling the movements of micro burner and measuring various thermal properties. The timer T_1 sets the time for flame impeachment at the specimen. The timer T_2 and T_3 starts simultaneously as the flame of specific height starts igniting the specimen. The time duration for flame propagation, from the point of ignition to the end of the specimen is noted by means of a timer T_2, as soon as flame reaches the cord, the cord burns and drops the dead weight tied at the end of cord. Dropping of deadweight releases the clip held by cord through tension. Releasing the clip held by cord stops the timer T_2.

When burning mass of the specimens reaches the end point, the burning time is recorded by means of timer T_3, Measurement of the time required for burning the specimen starts from the flame impeachment and up to the burning of specimen reaches the end of specimen. The silver plate attached to a thermocouple LM 35 (Fig.5.5) is fixed just under the rack for resting of specimen. The temperature of silver plate is continuously monitored and displayed by tutor (connected with timer) T_4, the record of temperature changes with respect to time interval of one second, is stored into a computer integrated by means of a designed circuit (Fig.5.4).

The code developed by C programming enables to use the measured thermal properties and finally plots a time and incident heat flux profile for complete test period. The plot is recorded until the room temperature is attained by the silver plate. The circuit uses supporting integrated circuits like IC 74573, IC7490 and ICADC 0809 for sensing and storing the data (Fig.5.4).

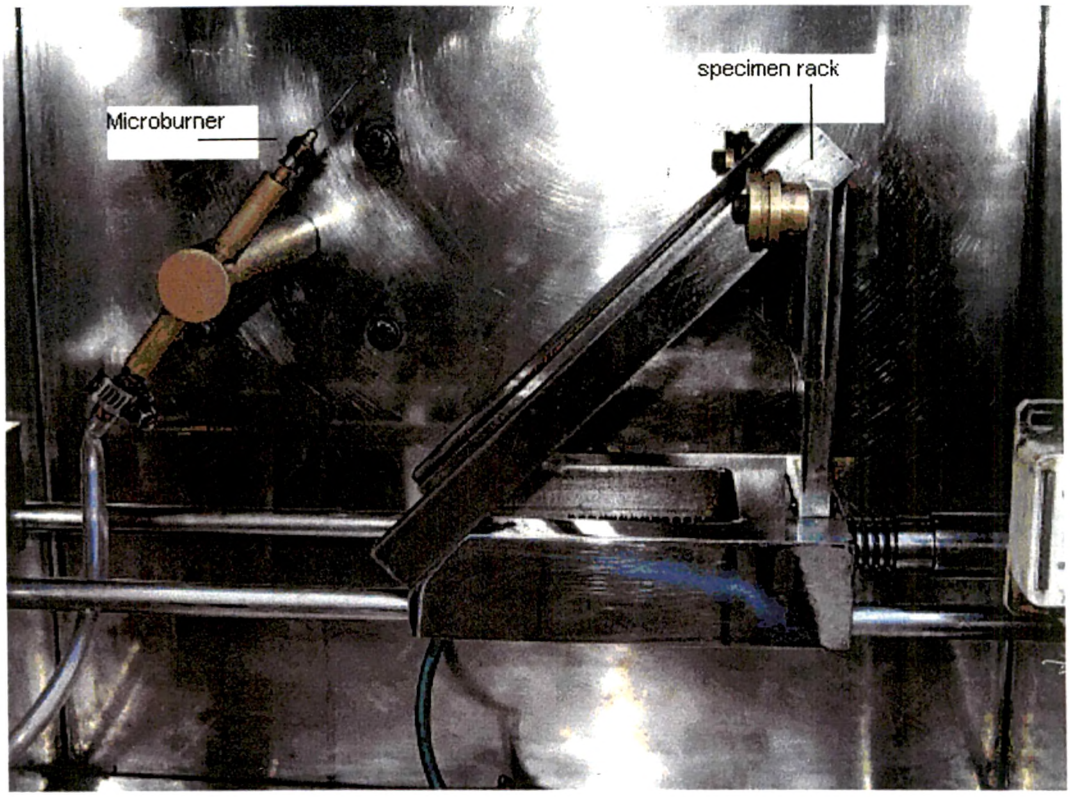

Fig. 5.2 Combustion chamber showing micro burner with 45° specimen rack

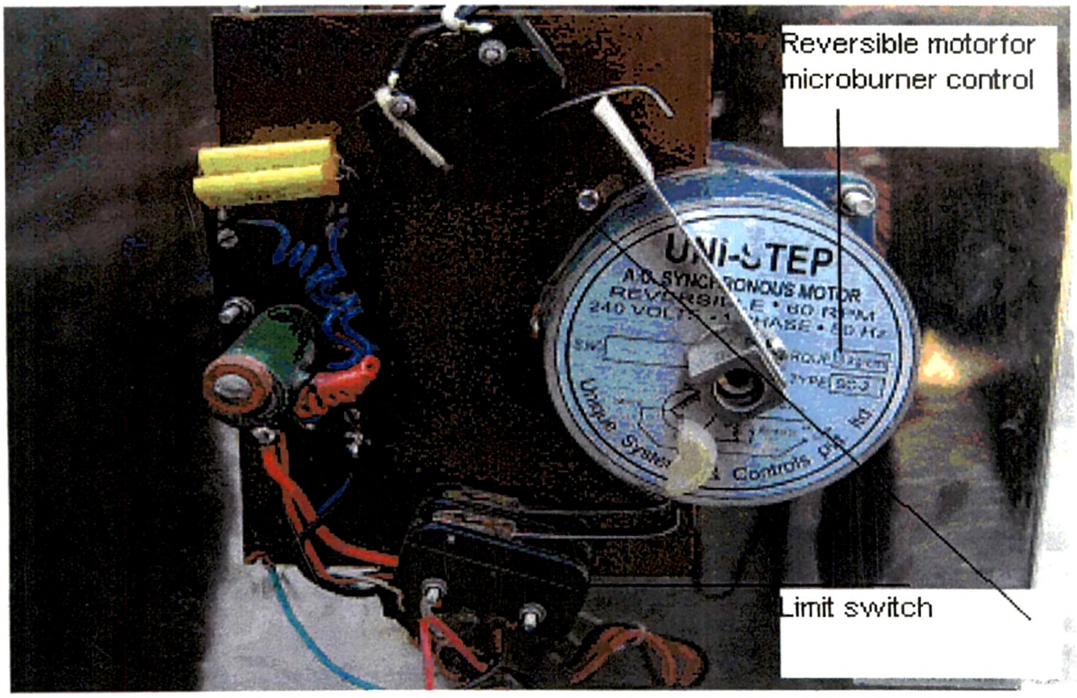

Fig. 5.3 Circuit for controlling micro burner movements and timings

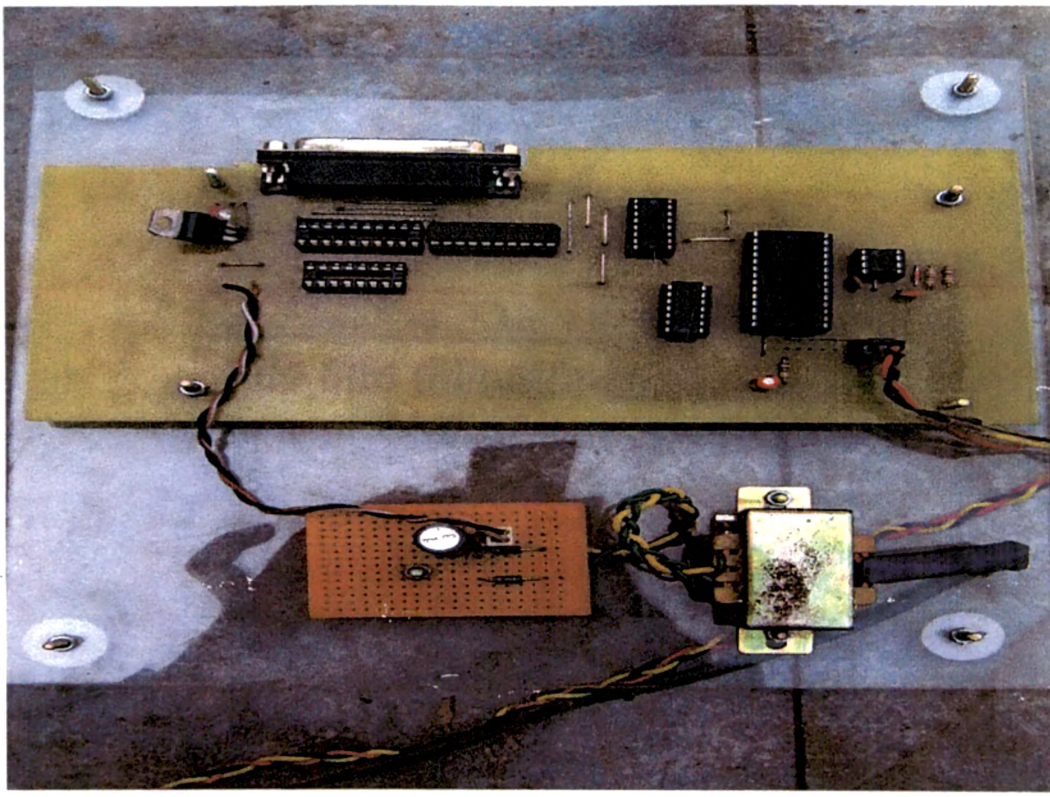

Fig. 5.4 Circuit details for tutor, timers and computer integration

Fig. 5.5 Thermocouple LM 35 mounted with fabric sample

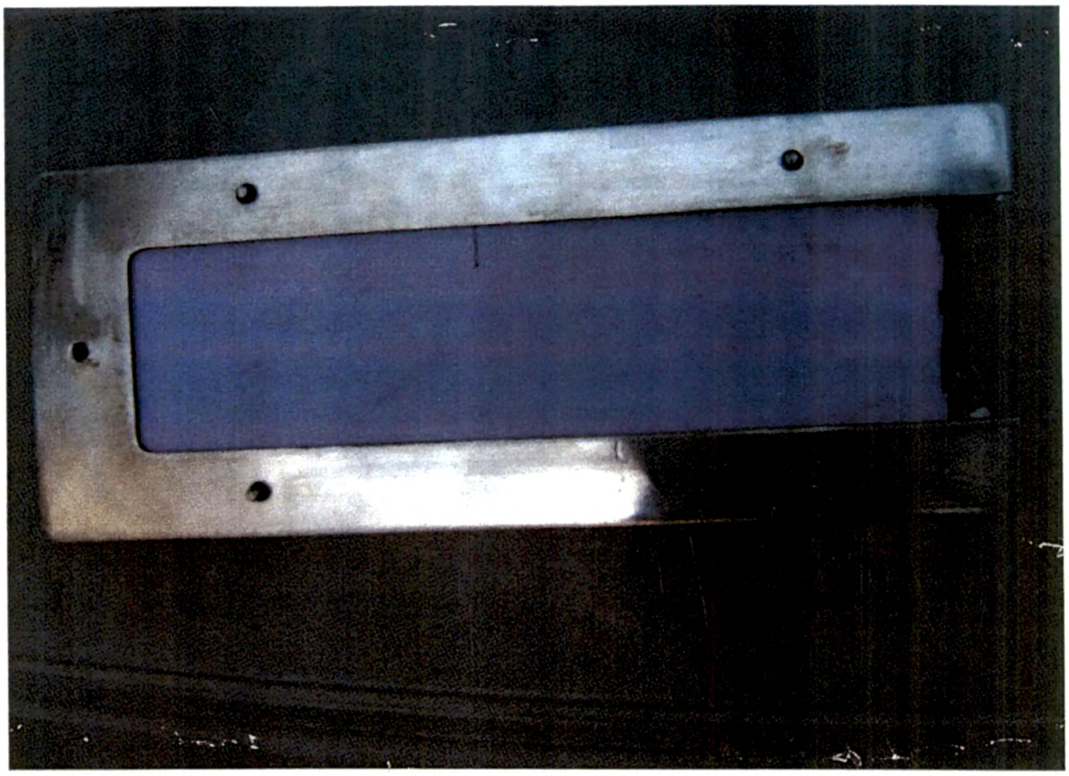

Fig. 5.6 Specimen holder

Fig. 5.7 Silver plate and thermocouple assembly

5.4 PREREQUISITES FOR FLAMMABILITY TEST

The following are the prerequisites and calibrations required before the actual test:

1. Adjust the distance of micro burner tip to the specimen, the distance D1 from the bottom line of the specimen to the micro burner tip to 13 mm at the vertical centre of the specimen and D2 between micro burner tip and specimen face should be 8 mm.
2. Adjust the length of the flame by means of a regulatory valve provided, the length should be maintained at 16 mm
3. Set timer T_1 at pre set time for flame impeachment for time equal to the ignition time (measured earlier as mentioned in section 5.7.1), T_2 and T_3 should be kept checked for zero mark during the start of the test.
4. Prepare at least 10 specimen of each standard sample.
5. Adjust the rack angle initially by adjusting the screws as per the angle of test, initially at 45° and finally at 90°.
6. Conduct the test in a draft free room at room temperature.

5.5 SAMPLE PREPARATIONS

1. Cut 150 mm x 50 mm samples from the fabric to be tested for the hazard potential test and prepare standard specimen for testing according to the actual wearing pattern of specific garment.
2. Condition the specimen to be tested, by drying in horizontal position in an oven for 30 minutes at 105°C, remove from the oven and place over anhydrous calcium chloride in desiccators until cool, but for not less than 15 minutes.

5.6 PROCEDURE OF FLAMMABILITY TEST

The following process steps should be followed for the Flammability Test

1. Mount the conditioned specimen inside the specimen holder frame; keep the specimen taught by tape fixations. Keep the specimen holder frame on to the specimen rack and hold the frame on to the rack by means of tongs. Ensure that there exists no gap between the specimen fabric down face with the silver plate, by keeping specimen taught

inside the frame and silver plate raised up to the face of specimen (Fig.5.6).

2. Open the gas control valve and lit the flame, adjusting flame length for 16 mm by means of a Gauge prepared for the same.
3. Place the stop cord above and parallel to the lower surface of the top frame at the top end of the specimen and hang with a dead weight.
4. Close the door of the combustion chamber and activate the starting switch, this starts the timing mechanism and will bring the micro burner to the face of the specimen for flame impeachment, for a preset time set in timer T_1. This pre set time should be always equal to the time for ignition (T_{ig}) As the flame propagates and reaches the stop cord, it breaks stop cord and drops the dead weight, stopping the timer T_2 recording and displaying flame propagation time in second.
5. As burning of specimen reaches the end of the specimen, it is recorded in at timer T_3 in seconds. This time is called as burning time.
6. Sensor LM 35 sense the changes of temperature with respect to time interval in seconds and simultaneously stores and develops a temperature-time profile with the help of integrated circuits and computer.
7. Due to recording of time at timers T_1, T_2, T_3 and temperature at tutor T_4 and by performing calculations mentioned in section 5.7, an Incident heat flux and time profile is plotted with the help of the developed program until the silver plate attains its initial room temperature.
8. Repeat the test for all 10 numbers of samples for an average value and repeat the test for 45° and 90° Depending upon the garment pattern the values of 45° or 90° should be used for correlations. In cases where the burning angle for the garment is not definite, a range of values from 45° to 90° should be used for co relation.
9. Correlate the average incident heat flux for initial 60 second with the stoll and chinata criteria for second degree burn injury prediction.
10. The total percentage of second degree of burn injury on total body surface area will define the hazard potentiality of the specimen.

5.7 CALCULATIONS OF THERMAL PARAMETERS

5.7.1 Measurement of Ignition Time (T_{ig})

Set the time for impeachment of flame for a time interval of 0.1 second, and note the time when the specimen ignites. For each interval a separate specimen should be used and average value of the 10 ignited specimen readings obtained as (T_{ig})

$$T_{ig} = \frac{T_{ig}1 + T_{ig}2 + T_{ig}3 + \ldots\ldots\ldots\ldots\ldots + T_{ig}n}{n}$$

Where, $T_{ig}1$, $T_{ig}2$, $T_{ig}3$ ......are the ignition time for specimens 1,2,3 etc. and n is the number of specimens.

5.7.2 Measurement of Flame Propagation Rate (FPR)

The flame is applied at the centre of the specimen and 13 mm above the bottom edge. Flame propagates up to the end of the specimen, where stop cord is situated, which is at distance of 137 mm from ignition point. The flame propagation time is expressed in cm/s and is given by

$$\text{Flame Propagation Rate} = \frac{\text{Distance traveled by flame}}{\text{Time required to travel the same distance}}$$

$$FPR = 13.7 / (T2 - T_{ig})$$

Where, T_{ig} is the ignition time and T2 is the total time taken by the flame to travel the distance from the time of flame impeachment up to the break of stop cord, noted by timer T_2.

5.7.3 Measurement of Burning Rate (BR)

The burning rate is calculated in terms of the time required to burn unit length of specimen. Length of specimen is 13.7 cm and the burning rate is calculated as follows

Burning rate = Time required to burn unit length of the specimen

$$\text{Burning Rate} = \frac{13.7}{\text{Time required to burn the fabric}}$$

$$BR = 13.7/T3 - T_{ig} \quad \text{cm/s}$$

Where, T3 is the time displayed by timer T_3 and T_{ig} is the time for ignition.

5.7.4 Measurement of Heat Absorbed (H_a)

The heat absorbed by the incident surface at a given time, is expressed in cal/cm^2 that depend on material properties. Specific heat of silver plate is 0.056 cal/°c/gm. Weight of silver plate is 1.3 gm and area used for exposure is 3 cm^2. Where, T_4 is the temperature of silver plate and T_r is the room temperature.

Heat absorbed (cal/cm^2) is given as

$$= \frac{\text{Rise in temp.at a given time} \times \text{Sp. heat of silver Plate} \times \text{Wt. of silver plate}}{\text{Volume of silver plate}}$$

$$H_a = \frac{(T_4 - T_r) \times 0.056 \times 1.3}{0.123}$$

Where, T_r is the room temperature (initial temperature recorded by silver plate) and T_4 is the temperature sensed / displayed by tutor.

5.7.5 Measurement of Incident Heat Flux

The heat flux is expressed as cal/cm^{2}s. It is defined as amount of heat incident per second per unit area of the incident surface.

Q_i = Heat absorbed x Burning rate

5.7.6 Average Incident Heat Flux

The measurement of average incident heat flux is measured by calculating the area under the incident heat flux and time curve.

5.7.7 Average Incident Heat Flux for Initial 60 Seconds (AIHF60)

The measurement of average incident heat flux is measured by calculating the area under the incident heat flux and time curve for initial 60 seconds. As for the entire specimen peak heat, release attains before 60 seconds and heat release during cooling is not taken into consideration for warning of the hazard potential.

5.7.8 Prediction of Burn Injury

Heat flux and burn injury correlations are useful for prediction of degree of burns. The average incident heat flux values are checked with Stoll and Chianta criteria given in Table 5.1. Accordingly, the specimen is graded for first or second degree burns. The average incident heat flux up to 60 seconds is calculated and taken into consideration as most of the entire specimen showed maximum heat flux values up to 60 seconds and later on cooling heat flux is not taken into consideration.Total percentage of burn injuries on will define the hazard potentially of the particular specimen. As shown, more the percentage of second degree burns, more will be hazard potential of a particular specimen.

Table 5.1 Stoll and Chianta 2nd Degree Burn Criteria

Time	Heat Flux to Cause 2nd Degree Burn		Total Energy Absorbed	
s	cal/cm^2 s	cal/cm^2	cal/cms^2	KJ/m^2
1	1.2	50	1.20	50
2	0.73	31	1.46	61
3	0.55	23	1.65	69
4	0.45	19	1.80	75
5	0.38	16	1.90	80
6	0.34	14	2.04	85
7	0.30	13	2.10	88
8	0.274	11.5	2.19	92
9	0.252	10.6	2.27	95
10	0.233	9.8	2.33	98
11	0.219	9.2	2.41	101
12	0.205	8.6	2.46	103
13	0.194	8.1	2.52	106
14	0.184	7.7	2.58	108
15	0.177	7.4	2.66	111
16	0.168	7.0	2.69	113
17	0.160	6.7	2.72	114
18	0.154	6.4	2.77	116
19	0.148	6.2	2.81	118
20	0.143	6.0	2.86	120
25	0.122	5.1	3.05	128
30	0.107	4.5	3.21	134

5.9 MATHEMATICAL MODEL FOR HEAT TRANSFER IN SKIN LAYERS

Among the various models to study the heat transfer in living tissues, the pennes equation is the most widely used one.[3] It is based on the classical Fourier law and simplified to study the bio-heat transfer and assessment of skin burns. The object of this model is to study the bio-heat transfer at various layers of skin for the injury prediction at various heat fluxes for a given time on the skin surface. This can be possible through presenting an implicit numerical solution of the pennes equation.

5.9.1 Bio-Heat Transfer Model

For prediction of temperature and burn injury at various layers of skin, the difference of thermo physical properties of structural skin layers have been considered. The mathematical description of the model may be represented in the following way.

Skin composed of three layers as shown in the Fig. 5.8.

Let x be the depth of the skin, y and z be the width (cells) of skin in other two directions. The depth x of the skin is divided into three layers of skin namely epidermis, dermis and hypodermis. The base of epidermis is at x_1, dermis at x_2 and hypodermis at x_3.

Let ρ_1, ρ_2, and ρ_2 be the density of epidermis, dermis and hypodermis respectively. C_1, C_2 and C_3 are the specific heat of epidermis, dermis and hypodermis respectively and C_b is the specific heat of blood. T_c is the temperature of core of skin at base of hypodermis and T_s be the temperature at the surface of the skin. k_1, k_2 and k_3 be the thermal conductivity of epidermis, dermis and hypodermis respectively. Q_i is the external incident heat flux and Q_m is the volumetric metabolic heat flux.

T_1, T_2, T_3 represents temperature of epidermis, dermis and hypodermis respectively. Suffices $_{1,\,2,\,3}$ represents respectively for epidermis, dermis and hypodermis layers of skin. For simplicity, the constant thermal parameters are assumed but variable Q_i is reserved. Fig.5.8 represents the human skin, which shows the practical situation.

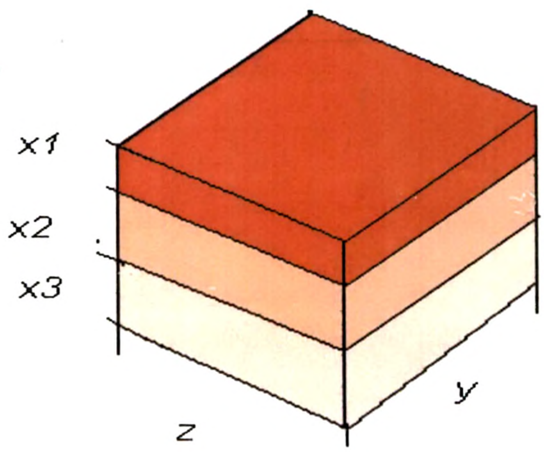

Fig. 5.8 Three-dimensional computational domain for numerical analysis

The three-dimensional model represents the body skin and the heat transfer mechanism may be represented by the following equations. viz.

For epidermis,

$$\rho_1 C_1 \frac{\delta T_1}{\delta t} = K_1 \frac{\delta^2 T_1}{\delta^2 x} + K_1 \frac{\delta^2 T_1}{\delta^2 y} + K_1 \frac{\delta^2 T_1}{\delta^2 z} + Q_{m1} + Q_{i1} \quad (1)$$

For dermis

$$\rho_2 C_2 \frac{\delta T_2}{\delta t} = K_2 \frac{\delta^2 T_2}{\delta^2 x} + K_2 \frac{\delta^2 T_2}{\delta^2 y} + K_2 \frac{\delta^2 T_2}{\delta^2 z} + W_b C_b (T_a - T_2) + Q_{m2} + Q_{i2} \quad (2)$$

For hypodermis

$$\rho_3 C_3 \frac{\delta T_3}{\delta t} = K_3 \frac{\delta^2 T_3}{\delta^2 x} + K_3 \frac{\delta^2 T_3}{\delta^2 y} + K_3 \frac{\delta^2 T_3}{\delta^2 z} + W_b C_b (T_a - T_3) + Q_{m3} + Q_{i3} \quad (3)$$

The Boundary conditions corresponding to the Fig. 5.8 are prescribed as follows:

For epidermis

$$T_0 = T_s + Q_m \,, \quad x = 0, \qquad T_c + K_1 \frac{\delta T_0}{\delta x} = T_1 \,, \quad x = x_1 \tag{4}$$

$$K_1 \frac{\delta T_0}{\delta y} = 0 \,, \quad y = 0, \qquad K_1 \frac{\delta T_0}{\delta y} = 0, \quad y = Y \tag{5}$$

$$K_1 \frac{\delta T_0}{\delta z} = 0 \,, \quad z = 0, \qquad K_1 \frac{\delta T_0}{\delta z} = 0, \quad z = Z \tag{6}$$

For Dermis

$$T_0 = T_s + Q_m, \,, \quad x = 0, \qquad T_c + K_2 \frac{\delta T_1}{\delta x} = T_2 \,, \,, x = x_2 \tag{7}$$

$$K_2 \frac{\delta T_1}{\delta y} = 0 \,, \quad y = 0, \qquad K_2 \frac{\delta T_1}{\delta y} = 0, \quad y = Y \tag{8}$$

$$K_2 \frac{\delta T_1}{\delta z} = 0 \,, \quad z = 0, \qquad K_2 \frac{\delta T_1}{\delta z} = 0, \quad z = Z \tag{9}$$

For Hypodermis

$$T_0 = T_s + Q_m, \,, \quad x = 0, \qquad T_c + K_3 \frac{\delta T_2}{\delta x} = T_3 \,, \quad x = X \tag{10}$$

$$K_3 \frac{\delta T_2}{\delta y} = 0 \,, \quad y = 0, \qquad K_3 \frac{\delta T_2}{\delta y} = 0, \quad y = Y \tag{11}$$

$$K_3 \frac{\delta T_2}{\delta z} = 0 \,, \quad z = 0, \qquad K_3 \frac{\delta T_2}{\delta z} = 0, \quad z = Z \tag{12}$$

Conduction Heat transfer relation between Epidermis and Dermis

$$Q_{1\text{-}2} = K_1 A_1 \frac{(T_1 - T_2)}{L_1} \quad (13)$$

Conduction Heat transfer relation between Dermis and Hypodermis

$$Q_{2\text{-}3} = K_2 A_2 \frac{(T_2 - T_3)}{L_2} \quad (14)$$

Where, X is the depth of the skin to be analysed in x direction, here the skin surface is defined as x = 0, while the body core at x = X. Y and Z are the widths of the skin in the y and z direction respectively. The other parameters are T_c the body core temperature, which is regarded as constant, T_s is the body surface temperature and the subscripts $_{1,\ 2,\ 3}$ are used for epidermis, dermis and hypodermis respectively. A_1 and A_2 are the cross sectional area between epidermis-dermis and dermis-hypodermis respectively for heat transfer. L_1 and L_2 are the length of epidermis and dermis respectively. The temperature calculated at different layers is used to predict the burn injury analysis as follows

Thermal injury assessments is done with the help of Henriques burn integral, Accordingly the burn injuries can be predicted, depending on the value obtained for injury factor 'Ω'.

$\Omega \leq 0.5$ at 80 μm, no tissue is damaged,

$0.5 < \Omega > 1.00$ at 80 μm 1st degree burns occurs

$\Omega \geq 1.00$ at 8 μm and $\Omega < 1.00$ at 2000μm, 2nd degree burns occurs

$\Omega \geq 1.00$ at 2000 μm, 3rd degree burns occurs

5.9.2 Numerical Solution

Using PDE solver software the partial differential equations in section 5.9.1, numerical values are required to be substituted for the necessary calculation for predicting the flow of heat. But the equation cannot be solved until knowing the actual values of temperature T_1, T_2 and T_3. Which need an accurate technique for measurement of temperature at basal layer of epidermis (x_1 = 80 μm), dermis (x_2 = 1920 μm) and hypodermis (x_3 = 5000 μm).

Values considered for solving the numerical scheme

x_1	= 80 μm,
x_2	= 1920 μm,
x_3	= 5000 μm,
ρ_1	=1150 kg/m^3,
ρ_2	=1200 kg/m,^{3}
ρ_3	=1000 kg/m^3.
C_1	= 3600 ^{o}kJ/kg,
C_2	=2400 ^{o}k J/kg,
C_3	= 3000 ^{o}k J/kg.
C_b	= 4000 ^{o}CJ/kg,
W_b	=0.5 kg/m^{3}s,
T_a	= 37° C,
T_c	=37° C,
T_s	=32.5° C,
k_1	=0.209 ^{o}k W/m,
k_2	=0.380 ^{o}k W/m,
k_3	=0.210 ^{o}k W/*m,*
Q_m	= 420 W/m^3,
Q_i	= K W/m,^{2}
A_1	= 1cm,^{2}
A_2	= 1cm,^{2}
L_1	= 1 mm, and
L_2	= 1 mm.