List of Research Publications

(I) Publications:


(II) Papers presented:

1. Thermoluminescence (TL) analysis of naturally occurring salt for sample weight selection for dosimetry studies, Kham Suan Pau, Ramesh Chandra Tiwari and B. Arun Kumar Sharma, (PANE-2010), 4th-6th October, 2010, Manipur University, Imphal.
2. Thermoluminescence (TL) study of Natural salt, Kham Suan Pau and Ramesh Chandra Tiwari, One day State Level Seminar on Recent Advances in Radiation Physics, 15th April, 2011, Mizoram University, Aizawl.


Brief Bio-data of the Author

Born in 24th January, 1976, the author completed his matriculation in 1991 from Government Kolasib High School, Pre-University (Science) in 1993 from Govt. Kolasib College, Bachelor of Science in 1997 from Pachhunga University College and Master of Science (Physics) with an M.Sc project work on ‘Properties of Feed Forward Boolean Networks’ in 2000 from North Eastern Hill University, Shillong.

The author has also completed Diploma in Radiological Physics in 2002 from Radiological Physics & Advisory Division, Bhabha Atomic Research Centre, Mumbai University.

Throughout under-graduate and post graduate studies, the author is a recipient of merit science scholarship. The author had attended an international and national conferences and presented papers. He also published articles in International scientific journals with Prof. R.C. Tiwari, Department of physics, Mizoram University. Further, the author has a brief teaching experience as a guest lecturer (2004-2007), diploma course in X-ray technology in Regional Institute of Paramedical and Nursing (RIPANS), Mizoram besides offering assignments on guidance and demonstrations in the subject matters to scholars.

In addition, the author is a Medical Physicist-cum-Radiological Safety Officer in Mizoram State Cancer Institute and is also The Head, Radiation Safety Agency, Government of Mizoram. He has extensive experiences of treatment planning in the field of radiotherapy and radiation safety especially $^{60}$Co unit, $^{192}$Ir unit and all types of X-ray generating equipments.
Thermoluminescence (TL) Analysis of Naturally Occurring Salt for Sample Weight Selection for Dosimetry Studies

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Abstract

Purpose of the present study is to select suitable sample weight for dosimetry studies in order to produce new and high performance TL materials for radiation dosimetry [1]. Powder samples of 10 mg, 20 mg, 30 mg and 40 mg weight were irradiated with gamma rays at doses 1, 2 and 6 Gy using 60Co source and TL glow curves were obtained for all the samples using TLD reader TL-1009I. Analysis of the glow curves showed different TL peak temperature, TL peak intensity and activation energy [2] values for the samples studied. Based on TL analysis, it was concluded that 20 mg sample weight is most suitable for patient dosimetry studies because TL peak temperature, TL peak intensity and activation energy were found to increase with increase in gamma radiation doses in lower range.

Keywords: Thermoluminescence, Gamma rays, Radiation Treatment

PACS No: 78.60.Kn, 07.85.-m, 81.40.Wx

Introduction

Thermoluminescence is a phenomenon of an insulator or semiconductor (sample) which can be observed when the solid is thermally stimulated [3]. Different authors
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used different sample weights in the form of powder, crystals or pellets. A temperature gradient of 2 °C within the sample may be assured by thickness of one particle layer [4]. On the other hand, the TL output increases with increase in the quantity of sample. Therefore, it is desirable to get a sample, which achieves good temperature gradient and good TL output. The sample weights giving maximum intensity in the temperature range of 180°C to 250°C are suitable for dosimetry purpose [5].

The present study aimed at selecting an appropriate sample weight or quantity in terms of maximum intensity ($I_{max}$), temperature of maximum intensity ($T_{max}$), and Dose Response from the TL glow curves. Here, we have considered the TL output of the samples as a basis to select suitable sample weight for dosimetry studies.

Materials and Methods
The Natural salt Dap Chi (local name) was extracted by evaporation of salty water, available in the state of Mizoram. The natural salt was crushed to fine powder, and given thermal treatment at 110 °C for 90 minutes in oven before irradiation. Samples of 10 mg, 20 mg, 30 mg and 40 mg were prepared at the Department of Biotechnology, Mizoram University using Digital Electronic Balance (Model-GF300, sensitivity-0.001g) manufactured by M/s A and D Company Ltd., Japan. These samples have an accuracy of + 2 mg. The weighed samples were preserved in air and light tight containers at room temperature of about 21 °C. Samples were irradiated from a $^{60}$Co gamma source at 1 Gy, 2 Gy and 6 Gy by placing them at the centre of a 10X10 cm$^2$ field opening at 80 cm treatment distance in a Cobalt Th780C machine. The dose rate of the $^{60}$Co source at the time of irradiation was 0.0253 Gy/sec. TL measurements of the irradiated samples were carried out after 48 hours in a commercial PC based TL reader, model TL1009I photomultiplier tube Hamamatsu/ET make Type No. 6095 (Nucleonix System Pvt. Ltd, Hyderabad). A second TL measurement gave background radiation with black body radiation. The heating rate used was 5 °C/sec (278 K/Sec) with the final temperature set to 400 °C.

Results and Discussions

Intensity Response Curve
TL glow curves for various sample weights showing one prominent peak in each case are given in Figures 1, 2 and 3. From the intensity curves in Figure 4, it is obvious that TL intensity increases with dose up to 2 Gy in 20 mg. Other samples show decrease in intensity with dose.
Figure 1: Intensity versus Temperature curves for samples irradiated with 1 Gy for various sample weights

Figure 2: Intensity versus Temperature curves for samples irradiated with 2 Gy for various sample weights

Figure 3: Intensity versus Temperature curves for samples irradiated with 6 Gy for various sample weights
Figure 4: Plot of Intensity versus Dose (1, 2 and 6 Gy) for 10, 20, 30 and 40 mg samples

Temperature Response Curve
From the temperature of maximum intensity ($T_{\text{max}}$) curves in Figure 5, almost constant $T_{\text{max}}$ is observed from 1 Gy to 2 Gy, except in 30 mg. Above 2 Gy, all samples show steep fall in $T_{\text{max}}$ with given dose.

Therefore, only 20 mg sample shows increase in intensity with dose from 1 Gy to 2 Gy with almost constant $T_{\text{max}}$ 489.8 K (216.8 °C).

Figure 5: Plot of Temperature of Maximum Intensity versus Dose (1, 2 and 6 Gy) for various sample weights

Dose Response Curve
A detector which has the property of linear relationship between thermoluminescence and absorbed dose is desirable [6] for TL studies. The absorbed dose is proportional to $n_0$, the total number of trapped electrons at time $t = 0$. This parameter $n_0$ is equal to the area under the glow peak [1]. Therefore, Integration area is plotted against
absorbed dose in Figure 6, where integration zone is taken from about 320 K – 540 K.

From Figure 6, it is obvious that only in 20 mg sample, an increase dose response from 1 Gy to 2 Gy is observed. The dose response for lower doses was tested by exposing 20 mg sample to lower dose of 0.5 Gy, which also showed increasing dose response as shown in Figure 7. This suggests that, the sample 20 mg can be used for TL studies in the lower doses up to 2 Gy.

**Figure 6:** Plot of Integration area versus Dose (1, 2 and 6 Gy) for 10, 20, 30 and 40 mg samples

**Figure 7:** Plot of Integration Area versus Dose (0.5, 1, 2 and 6 Gy) for 20 mg sample weight

**Interpretation**
The samples of natural salt were extracted from salty water by evaporation. Therefore, the samples are expected to contain impurities. These impurities may be monovalent, divalent or trivalent atoms located at the lattice site of salt. The host lattice is expected to contain positive and negative ion vacancies. Therefore, recombinations like F-centre halogen molecule (F-H) recombination, recombination due to Impurity Vacancy (IV) dipoles are expected.

Since the TL glow curves have one prominent peak (Figure 1, 2, and 3), we
presumed that radiative recombination take place at one type of TL centres. The F-centre annealing assumes importance in TL studies. At 152 °C (425 K), about 25 % of F-centres get thermally annealed and the centres are completely erased at about 156 °C (429 K) [7]. Therefore, the TL glow peak observed at about 391 K for samples irradiated at 6 Gy in Figure 3 may be due to F centre annealing and F-H recombination. The IV dipole recombination is not likely for 6 Gy [6], because at higher doses the effect of irradiation on the pre-existing impurity-vacancy (IV) dipoles and the concentration of IV dipole decreases with imparted dose. The effect of heavily irradiated samples had been reported [8] which suggests that light emission is forbidden in interstitial F-centre recombinations, in addition to recombination, in which light emission is possible as in less irradiated samples.

On the other hand, recombination due to the IV dipole is presumed that on irradiating the sample, electrons from the impurity centres are ejected and trapped in the nearby negative ion vacancies. On heating the sample with constant heating rate of 5 °C/s (278 K), the trapped electrons are released and recombined at the emission centres. The TL emission at about 490 K for 10 mg and 20 mg are believed to be due to recombinations at IV dipoles formed as aggregates as shown in Figure 1 and 2.

Most of the TL glow curves contain one prominent peak at about 490 K with or without smaller peaks on either shoulders. This may be due to post irradiation storage at room temperature for 48 hours, where some energy may be available which is sufficient to destroy TL centres corresponding to lower temperature peaks.

The presence of impurities enhances traps. However, electrons may also get trapped at the impurities thus converting a trivalent impurity to divalent impurity or a divalent impurity to a monovalent impurity. The effect of these impurities on TL intensity may depend on their concentrations and the type of impurity content. Therefore, the TL peaks observed at about 440 K for 30 mg and 40 mg may be due to electrons trapped by impurities thereby lowering the energy of emission as shown in Figures 1 and 2.

Using the simple empirical formula \( E=23kT_{\text{max}} \) [9], the \( T_{\text{max}} \) for 10 mg and 20 mg irradiated at 1 Gy and 2 Gy respectively is about 490 K, gives activation energy 0.97 eV. This value of \( E \) being higher than other activation energy 0.77 eV and 0.87 eV for other peaks may prove the stability of 20 mg peaks at doses < 2 Gy. The values of parameters are given in Table 1.

<table>
<thead>
<tr>
<th>Dose</th>
<th>10 mg</th>
<th>20 mg</th>
<th>30 mg</th>
<th>40 mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>( T_{\text{max}} ) (K)</td>
<td>( E ) (eV)</td>
<td>( T_{\text{max}} ) (K)</td>
<td>( E ) (eV)</td>
</tr>
<tr>
<td>1 Gy</td>
<td>32200</td>
<td>495.14 (K)</td>
<td>0.98 (eV)</td>
<td>27400</td>
</tr>
<tr>
<td>2 Gy</td>
<td>30100</td>
<td>490.47 (K)</td>
<td>0.97 (eV)</td>
<td>34000</td>
</tr>
<tr>
<td>6 Gy</td>
<td>22700</td>
<td>463.43(K)</td>
<td>0.91 (eV)</td>
<td>25600</td>
</tr>
</tbody>
</table>

Table 1: TL peak intensity (\( I_{\text{max}} \)), Peak Temperature (\( T_{\text{max}} \)) and Activation energy \( E=23kT_{\text{max}} \)
Conclusion
The TL glow curves of different sample weights (10, 20, 30, and 40 mg), irradiated with different doses were studied. The temperature corresponding to maximum intensity was about 217 °C (490 K) which lies in the suitable temperature range 180 °C – 250 °C (453 K – 523 K) for dosimetry purpose. Out of the different samples studied, 20 mg is the only sample which gives increase in intensity with dose, increasing dose response in lower doses (0.5 Gy to 2 Gy) and high enough temperature of maximum intensity. Thus the 20 mg can be taken as suitable sample weight for TL studies in the lower doses up to 2 Gy.

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Abstract

The aim of the present study was to investigate the potential of the naturally occurring salt for the dosimetry purposes, using TL. The fine powder samples (20 mg) were irradiated by γ-rays from 500 mGy to 2500 mGy by using Theratron-780 Cobalt-60 source, however, this paper discusses about 500 mGy only. The TL glow curve peak parameters were studied by using Chen’s peak shape equation. TL glow curves were compared with fitted curves using glow curve deconvolution (GCD) method by using Kitis expression. The kinetic parameter values (E, b and s) so calculated, are in good agreement with those available in literature. The calculated energy values were also verified by using various heating rate (VHR) method. $\chi^2$ test and figure of merit (FOM) calculation was done to accept the goodness of fit between the curves. Fading studies of the sample showed a good fitting between the curves. The analysis suggests that natural salt should be considered for dosimetry purposes.

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KEYWORDS and PACS

Keywords

- evaporation
- dosimetry
- temperature measurement
- calibration

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Thermoluminescence (TL) Analysis and Fading Studies of Naturally Occurring Salt Irradiated by 500 mGy Gamma Rays

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Abstract. The aim of the present study was to investigate the potential of the naturally occurring salt for the dosimetry purposes, using TL. The fine powder samples (20 mg) were irradiated by γ-rays from 500 mGy to 2500 mGy by using Theratron-780C Cobalt-60 source, however, this paper discusses about 500 mGy only. The TL glow curve peak parameters were studied by using Chen’s peak shape equation. TL glow curves were compared with fitted curves using glow curve deconvolution (GCD) method by using Kitis expression. The kinetic parameter values (E, b and s) so calculated, are in good agreement with those available in literature. The calculated energy values were also verified by using various heating rate (VHR) method. χ² test and figure of merit (FOM) calculation was done to accept the goodness of fit between the curves. Fading studies of the sample showed a good fitting between the curves. The analysis suggests that natural salt should be considered for dosimetry purposes.

Keywords: Thermoluminescence, dosimetry, FOM, kinetic Parameters, fading, natural salt
PACS: 78.60.kn, 87.53.Bn, 84.60.Bk

INTRODUCTION

Thermo luminescence is a phenomenon of an insulator or semiconductor (sample) which can be observed when the solid is thermally stimulated [1]. The TL glow curve is considered as an array of connected points where the value at any point is a consequence of TL law [2]. The main peak temperature of 180 C – 250 C (453 K - 523 K) is considered to be suitable for dosimetry purpose because this temperature is high enough, activation energy $E > kT$ for trap emptying and low enough for black body interference [3], which is achieved in our experiment.

MATERIALS AND METHODS

Natural salt extracted by evaporation method was crushed to fine powder and heat treated at 110 C for one and half hour. The TL measurements of the irradiated samples were carried out in a commercial PC based TL reader, model TL1009I PMT Hamamatsu/ET make (Nucleonix System Pvt. Ltd, Hyderabad). The samples kept in air/light tight containers, stored at room temperature of about 298 K, were analyzed within 2 hours, 2 days and 4 days after irradiation. The Heating rate was 5 C/sec with final temperature 400 C. A background reading was taken from un-irradiated sample and subtracted from the irradiated sample reading. The TL glow curve obtained from immediate reading (< 2 hours) has apparently two glow peaks, whereas as each of the TL glow curves obtained after 2 days and 4 days has only one main glow peak. For the purpose of fitting the TL peak at around 476 K, we apply the general order Kitis’ expression [4] for GCD in the form $I(I_M, E, T_M, T)$ as shown in equation 1.

$$I(T) = I_M b^{rac{E}{kT}} \exp \left( \frac{E}{kT} \frac{T - T_M}{T_M} \right) \times \left( b - 1 \left( 1 - \frac{2kT}{E} \right) \frac{T^2}{T_M^2} \exp \left( \frac{E}{kT} \frac{T - T_M}{T_M} \right) \right)$$

where, $b$ is order of kinetic, $I_M$ is the maximum intensity, $T_M$ is the temperature of maximum intensity and $k$ is Boltzmann constant. The activation energy $E$ was also evaluated by VHR method [5] with heating rate β at 2 C/sec and 3 C/sec and applying the general order expression,

$$E = \frac{kT_M^2}{T_M - T_{M1}} \ln \frac{I_{M1}}{I_{M2}}$$
Where, \( T_M \) and \( I_M \) are the temperature and intensity of maximum TL peak respectively with \( \beta \) kept at 2 C/sec. Similarly \( T_M \) and \( I_M \) are for 3 C/sec. This method has an error less than 1 % for any order of kinetics \((1.1 < b < 2.5)\). The frequency factor \( s \) was obtained from equation (3).

\[
s = \frac{\beta E}{kT \mu} \frac{1}{1 + (b - 1) \frac{2kT \mu}{E}} \exp \left( \frac{E}{kT_M} \right)
\]

The reliability of the fitting was checked with two methods [6,7], the Figure of Merit (FOM) and \( \chi^2 \). In both cases the summation extends over experimental data points from 450 K to 530 K. The FOM is given by equation (4) as,

\[
FOM = \frac{\sum |y_{\text{experimental}} - y_{\text{fit}}|}{\sum y_{\text{fit}}}
\]

where \( y_{\text{experimental}} \) and \( y_{\text{fit}} \) represent the experimental TL intensity data and the values of the fitting function, respectively. The \( \chi^2 \) is given by

\[
\chi^2 = \sum_{i=1}^{k} \frac{(O(I_j) - E(I_j))^2}{E(I_j)}
\]

where \( i \) is the effective number of classes, \( O(I_j) \) is the observed frequency and \( E(I_j) \) is the expected frequency. The conventional value of 5 \% level of probability is taken as critical limit for the acceptability of the fitting. Finally, using equation (6), fading was analyzed by plotting normalized TL vs. Days [3].

\[
\Phi(t_c) = \frac{D_o}{F_c \exp(\lambda t_c)}
\]

Where \( \Phi(t) \) is the total TL light of a given peak in the glow curve, \( t \) is the time of storage of the irradiated sample, \( \lambda = s \exp(-\frac{E}{kT}) \) is the decay constant, \( F_c \) is the calibration factor of the TL system in dose/TL and \( D_o \) is the irradiation dose.

**RESULTS AND DISCUSSIONS**

The experimental TL glow curves of natural salt and readouts within 2 hours, 2 days and 4 days at constant heating rate 5 C/sec are shown in Fig. 1.

![TL glow curves of natural salt 500 mGy 60Co \( \gamma \)-ray irradiation with \( \beta \) constant at 5 C/sec.](image)

The peak shape method analysis for the sample at the second glow peak are given in Table 1.

**TABLE 1. The peak parameters of the natural salt.**

<table>
<thead>
<tr>
<th>Time</th>
<th>( T_M(K) )</th>
<th>( \omega = T_2 )</th>
<th>( \delta / \omega )</th>
<th>( I_M )</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2 hours</td>
<td>478.63</td>
<td>55.7</td>
<td>0.446</td>
<td>251</td>
</tr>
<tr>
<td>2 days</td>
<td>477.5</td>
<td>54.4</td>
<td>0.45</td>
<td>250</td>
</tr>
<tr>
<td>4 days</td>
<td>74.06</td>
<td>54</td>
<td>0.44</td>
<td>218</td>
</tr>
</tbody>
</table>

The value of the symmetry factor \( \mu \) is in between 0.42 and 0.52 for the 1st and 2nd order kinetics respectively. The activation energies obtained from this method are presented in Table 2.

**TABLE 2. The activation energy obtained from TL glow curves by peak shape method.**

<table>
<thead>
<tr>
<th>Time</th>
<th>( E_r )</th>
<th>( E_{rd} )</th>
<th>( E_{rd} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2 hours</td>
<td>0.87eV</td>
<td>0.91eV</td>
<td>0.87eV</td>
</tr>
<tr>
<td>2 days</td>
<td>0.92eV</td>
<td>0.95eV</td>
<td>0.90eV</td>
</tr>
<tr>
<td>4 days</td>
<td>0.90eV</td>
<td>0.93eV</td>
<td>0.87eV</td>
</tr>
</tbody>
</table>

The value of \( E \) obtained by this method is approximately 0.9 eV. The peak shape method apply \( T_M \) and the temperature of half maximum intensity \( T_1 \) and \( T_2 \) on either side of \( T_M \) from the glow curves. Therefore, if a glow curve consists of a linear combination of more than one TL glow peaks, this method may under estimate the value of \( E \). The data was again analyzed with GCD of general order kinetics by using equation (1). The curve fittings and parameters obtained from this method are presented in Fig. 2(a), (b), (c) and in Table 3.
The frequency factor \( s \) in our experiment is in the range \( 10^{12} \) s\(^{-1}\) which lies in the physically realistic range \([8]\) of \(10^{12}\) to \(10^{14}\) s\(^{-1}\) as shown in Table 3. The value of \( E \) obtained from both VHR method and GCD has good agreement. No thermal lag correction is considered because \( \beta \) used are the minimum heating rates available with the TL reader. The \( \chi^2 \) values are acceptable at 6 degrees of freedom (d.f.).

**Fading**

The experimental TL glow curves shows that almost all the lower temperature peaks were faded within 2 days, \( I_M \) decreases with time, and the shape of the TL glow curves are more or less stable with time \((b=1.5)\). The lower temperature TL glow peak at about 370 K in the immediate reading may be assumed as consisting of combination of smaller TL peaks rather than a single isolated peak. In contrary to this, if a single glow peak makes the lower temperature peak, its trap depth may be approximately \((T_M/500)\) 0.74 eV and its fading will be much slower as shown by the theoretical fading in Fig. 3.

**FIGURE 3.** The theoretical fading of the lower temperature peak.

It was also observed from the experimental TL glow curve that the \( (T_M) \) of the higher temperature peak is 478.63 K within 2 hours, which decreased to 476.79 K after 2 days and 474.06 K after 4 days. The intensity also decreased by 0.39 % and 13.14 % after 2 days and 4 days respectively. However, the theoretical studies showed negligible fading. In Fig. 6, normalized \( \Phi(t) \), is plotted against \( t \) for both theoretical and experimental.

**FIGURE 4.** The fading of natural salt irradiated with 500 mGy \(^{60}\)Co \( \gamma \)-ray is plotted between normalized TL versus days.

**CONCLUSION**

The stability of the main TL glow peak at about 476 K up to 2 days and good agreement of GCD and experimental data indicates that the trapping parameters \( E, s \) and \( b \) obtained from our analysis are reliable. With these parameters, one can easily reconstruct Fig. 6 at any stage of fading with high accuracy within 2 days. The kinetic parameters, \( T_M \) and fading stability also indicate that the natural salt can be used for dosimetry study. As stability of TL...
signal as a function of storage time and temperature is a requirement of any good TL dosimeter, the natural salt can be used for TL dosimeter within 2 days.

REFERENCES


Fading Studies of Natural Salt for Dosimetry Applications

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ABSTRACT

Fading at room temperature is one of the most important properties of TL material. The purpose of the present studies is to find out the suitability of natural salt extracted from rivers of Mizoram for dosimetry applications. TL analysis of the gamma irradiated samples stored at room temperature was done within 2 hours, after 48 hours and 96 hours of irradiation. Experimental glow curves were fitted by using Kitis et al general order expression and the fitting parameters were obtained by authors using GCD method. TL analysis of samples showed good dosimetry peaks at about 205 C. Our studies indicate that the natural salt may be considered for dosimetry applications within 48 hours after gamma irradiation.

INDEX TERMS

- Dosimetry, Equations, Fading, Fitting, Materials, Radiation effects, Temperature measurement
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  - Controlled Indexing
    - dosimetry, gamma-ray effects, rivers, thermoluminescence
  - Non Controlled Indexing
    - GCD method, Mizoram river, dosimetry application, fading properties, fitting parameters, gamma-ray irradiation, glow curve deconvolution method, natural salt, temperature 293 K to 298 K, thermoluminescence material, time 2 h, time 48 h, time 96 h

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Fading Studies of Natural Salt for Dosimetry Applications

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Abstract—Fading at room temperature is one of the most important properties of TL material. The purpose of the present studies is to find out the suitability of natural salt extracted from rivers of Mizoram for dosimetry applications. TL analysis of the gamma irradiated samples stored at room temperature was done within 2 hours, after 48 hours and 96 hours of irradiation. Experimental glow curves were fitted by using Kitis et al general order expression and the fitting parameters were obtained by authors using GCD method. TL analysis of samples showed good dosimetry peaks at about 205 C. Our studies indicate that the natural salt may be considered for dosimetry applications within 48 hours after gamma irradiation.

Keywords—thermoluminescence; fading; natural salt; dosimetry; gamma irradiation

I. INTRODUCTION

Thermoluminescence (TL) is a phenomenon of an insulator or semiconductor (sample) which can be observed when the solid is thermally stimulated [1]. A plot of TL intensity against temperature is called a TL glow curve. A TL glow curve is considered as an array of connected points where the value at any point is a consequence of TL law [2]. A TL glow curve may consist of one or more TL glow peaks. A TL glow curve which consists of more than one TL glow peaks cannot be analyzed with simple technique. Many methods of analysis such as Initial rise method, peak shape method, whole glow curve method and curve fitting method had been developed to interpret the physical phenomena and even software were developed to identify the main TL glow peaks and presence of satellite peaks. Computerized glow curve deconvolution is one of such software which requires only few parameters to reproduce/fit the experimental glow curve. This process is useful when overlapping glow peaks are present.

In this paper, Kitis et al general order equation of the form \( I(\lambda, E, T) \) is used to fit and analyze the experimental TL glow curve. This equation uses \( T \) as an adjustable parameter, whereas \( \lambda \) and \( E \) are available from the experimental data. The authors used computer spread sheet and obtained kinetic parameters. The authors also used the different parameters obtained from their analysis to study fading of their TL materials. The TL material is natural salt obtained from salty water from the rivers in Mizoram. Fading is studied at 48 hour and 96 hours with respect to TL reading obtained immediately (less than 2 hours) after irradiation and the results were reported in this paper. The main peak temperature of 180 C – 250 C is considered to be suitable for dosimetry purposes because this temperature is high enough, activation energy \( E > kT \) for trap emptying and low enough for black body interference [3], which is also achieved in our experiment at the 4th peak.

This paper also includes the whole glow curve method to calculate \( n_0 \), the number of trapped electrons at time \( t = 0 \). This value is estimated from the area under the glow curve, by summing the TL intensities multiplied by the temperature interval \( \Delta T \), between TL measurements and by dividing with the heating rate \( \beta \). The \( \Delta T \) in the linear region of the linear profile is 4.8 C/s and heating rate used is 5 C/s.

In this work we demonstrate the simulation of relevant processes related to TL phenomena of irradiated natural salt using generated parameters obtained from the GCD analysis. The findings were compared and discussed with the experimental results.

II. MATERIALS AND METHODS

The natural salt Dap Chi (local name) was extracted by the process of evaporation of salty water, available in the state of Mizoram. The natural salt was crushed to fined powder and given thermal treatment at 110 C for 90 minutes in even before irradiation. Samples of \( 20 \pm 2 \) mg were used for each measurement. Samples were irradiated from \( ^{60} \)Co gamma source at a low dose of 0.5 Gy from a cobalt Th780C machine. The dose rate of the cobalt source at the time of irradiation was 0.0253 Gy/s. TL measurements of the irradiated samples were carried out within 2 hours, 48 hours and 96 hours in a commercial PC based TL Reader, model TL1009I photomultiplier tube Hamamatsu/ET make type no 6095 (Nucleonix System Pvt. Ltd., Hyderabad). A second TL measurement gives background radiation with black body radiation. The TL glow curves presented are after background subtraction. The heating rate used was 5 C/s with final temperature set to 400 C.

The number of trapped electron at time \( t = 0 \) can be written as
where \( \Delta T \) the temperature interval between TL measurements, and \( \beta \) is the heating rate.

The TL intensity may be written \([9]\) as

\[
I(T) = I_M \left( \frac{b}{\beta} \right) \exp \left( \frac{E}{kT} \right) \left( \frac{T-T_m}{T_m} \right) \times \left[ (b-1) \left( \frac{2kT_e}{E} \right)^{\frac{T_m^2}{T_e}} \exp \left( \frac{E}{kT} \right) \left( \frac{T-T_m}{T_m} \right) + 1 + \frac{(b-1)2kT_e}{E} \right]^{(b-1)}
\]

where \( I_M \) is the maximum intensity of the TL peak and \( T_M \) is its temperature.

One may also deduced the frequency factor \( s \) as

\[
s = \left( \frac{\beta E}{kT_m^2} \right) \left( \frac{1}{1 + \frac{(b-1)2kT_m}{E}} \right) \exp \left( \frac{E}{kT_m} \right)
\]

Chen’s expression for general order has variable \( T \) which can be obtained from the experimental data.

The reliability of the fitting is tested with the help of Figure of Merit (FOM) \([9]\), which is defined as

\[
FOM = \frac{\sum_p |y_{experimental} - y_{fit}|}{\sum_p y_{fit}}
\]

where \( y_{experimental} \) and \( y_{fit} \) represent the experimental TL intensity data and the values of the fitting function respectively.

The procedure starts with selecting a prominent peak or a peak which seems to be isolated. The temperature and intensity of such peak and as well as some assumed values of \( E \) and \( b \) were substituted to Kitis expression (equation 2). The \( E \) and \( b \) values are usually started from 1.0 eV and 1 respectively and depending upon the fitting between experimental and fitted curves, \( E \) and \( b \) were adjusted to get the best fit. The smaller is the value of \( E \) the bigger is the curve. The \( b \) value is selected between 1 and 2. the higher temperature peak (peak 4) has \( T_M=205 \) C and \( I_M=251 \). the \( E \) and \( b \) value which give the best fit on the second half of this peak is found to 1.1 eV and 1.5 respectively. With this value of \( E, s \) is found to be 5.78x10^{12}.

Once the most prominent peak is fitted, it is possible to fit the remaining portion of the glow curve by assuming that; a) any point on a TL glow curve at a given temperature may be a linear combination of two or more TL points at the same temperature and belonging to smaller TL curves, and b) the fitting is started from higher temperature and move towards the lower temperature side. Therefore, once the peak 4 is fitted, the next lower temperature peak can be fitted by similar process. The point of divergence of the fitted curve from the experimental curve can be used as a guide. And finally the combination of fitted peaks which best fit the experimental curve is chosen. By this process the whole experimental TL glow curve can be fitted with four TL peaks as shown in figure 2 and fitting parameters in table 1.

### III. RESULTS AND DISCUSSIONS

The TL glow curves of gamma irradiated natural salt at 2 hours, 48 hours and 96 hours are shown in Fig. 1. The GCD spread sheet analysis of 2 hours TL curve by using equation (2) showed four TL glow peaks as shown in Fig. 2.

![Figure 1. Experimental glow curves at less than 2 hours, 48 hours and 96 hours.](image1.png)

![Figure 2. Glow Curve Deconvolution of natural salt irradiated to 0.5 Gy and measured within 2 hours.](image2.png)

Several studies on fading of natural salt and their application as retrospective dosimeter had been done by many researchers \([4,5,6,7]\).

<table>
<thead>
<tr>
<th>Time</th>
<th>Peak</th>
<th>( I_M )</th>
<th>( T_M ) (C)</th>
<th>( E ) (eV)</th>
<th>( s ) (s^{-1})</th>
<th>( b )</th>
<th>( T ) (day s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 hrs</td>
<td>P1</td>
<td>80</td>
<td>89</td>
<td>0.8</td>
<td>2.65 \times 10^{12}</td>
<td>1.4</td>
<td>1.97 \times 10^6</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>98</td>
<td>107</td>
<td>0.65</td>
<td>5.93 \times 10^{10}</td>
<td>1.3</td>
<td>2.36 \times 10^6</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>30</td>
<td>155</td>
<td>0.7</td>
<td>2.84 \times 10^{10}</td>
<td>1.3</td>
<td>4.14 \times 10^6</td>
</tr>
<tr>
<td></td>
<td>P4</td>
<td>251</td>
<td>205</td>
<td>1.1</td>
<td>5.78 \times 10^{12}</td>
<td>1.5</td>
<td>1.26 \times 10^6</td>
</tr>
</tbody>
</table>

Table 1. Fitting parameters obtained using GCD from the experimental TL glow curve from Fig. 2.
These parameters were used to simulate the fading of each peak by using equation (2) and the results were presented in Fig. 3 with \( t \) taken as 2 hours, 48 hours and 96 hours. The total theoretical curve for 2 hours, 48 hours and 96 hours as a result of linear combination of individual TL peaks is presented in Fig. 4.

![Figure 3. Simulation of glow peaks 1, 2, 3 and 4.](image)

The fading of the whole curve, both experimental and theoretical glow curves were shown in Fig. 5.

![Figure 5. The decay of experimental TL intensity and theoretical intensity.](image)

**TABLE 2. Percentage of deviation of experimental curve with respect to theoretical curve**

<table>
<thead>
<tr>
<th>Hours</th>
<th>2h</th>
<th>48h</th>
<th>96h</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 205 ± 28°C</td>
<td>0.00%</td>
<td>1.56%</td>
<td>16.35%</td>
</tr>
<tr>
<td>P2 205 ± 28°C</td>
<td>0.00%</td>
<td>0.30%</td>
<td>0.54%</td>
</tr>
<tr>
<td>Whole curve 70°C to 239°C</td>
<td>0.00%</td>
<td>35.96%</td>
<td>42.36%</td>
</tr>
<tr>
<td></td>
<td>0.00%</td>
<td>36.23%</td>
<td>42.28%</td>
</tr>
</tbody>
</table>

The P4 peak is contaminated by the neighboring P3 peak, which still exist at 96 hours, whereas both theoretical and experimental P1 and P2 peaks almost decayed completely at 96 hours.

**IV. CONCLUSION**

The MS Excel spread sheet analysis could simulate the experimental glow curve in to four TL peaks. The experimental glow curve beyond 239°C is not fitted because the TL curve in this portion is distorted and perhaps due to residual background.

An analysis of the TL glow obtained within 2 hours showed that the experimental TL glow curve consist of four TL peaks. The peaks P1 at 85°C and P2 at 107°C, faded almost completely within 48 hours. The theoretical analysis also showed that the peak P3 at 155°C, faded slowly and P4 at 205°C was very stable up to 96 hours. However, the experimental fitted curve...
showed that P4 faded very fast from 48 hours to 96 hours. The divergence of the experimental curve from the theoretical curve at 48 hours is 1.56 % and at 96 hours is 16.56 %. Therefore, the TL material (natural salt) can be utilized within 48 hours for the purpose of TL dosimetry, without much correction. The fading at room temperature is one of the important considerations in any TL material. The position of P4 at around 205 °C is a good dosimetry peak. The consistency of $s$ (approximately $10^{12}$) for P4 for 2 hour, 48 hour and 96 hour (48 hour and 96 hour not shown in this paper) also lies in the physically realistic range of $10^{12}$ to $10^{14}$.

REFERENCES

Thermoluminescence (TL) Response of Natural Salt by Various Heating Rate (VHR) method for Dosimetry Applications

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Abstract

Thermoluminescence (TL) response of natural salt obtained from the rivers of Mizoram by evaporation method has been studied for its possible application in dosimetry. It is expected that the natural salt will essentially contain NaCl with other impurities. VHR method is important to analyse glow curves with changing heating rate. It has been observed that glow curves for various heating rates ($\beta = 2, 3, 4$ and $5 \, C/Sec$) contained two prominent peaks; however, only higher temperature peaks ($150 – 300 \, C$) were analysed. With increase in $\beta$, it was found that the TL peaks shift towards higher temperature and intensity of peaks decreases. Decrease in intensity may be attributed to thermal quenching. Thermal Lag Correction (TLA) for all temperatures of maximum intensity ($T_M$) were calculated and TLA was found to decrease with increase in $\beta$. Present study suggests that our sample may be a suitable candidate for dosimetry applications.

Keywords: thermoluminescence, thermal lag (TLA) correction, natural salt, various heating rate (VHR) method, dosimetry

1. Introduction

Thermoluminescence (TL) is the thermally stimulation emission of light following the previous absorption of energy from radiation [1]. The output of a TL is a glow curve that yield information about the kinetic parameters such as activation energy ($E$), and the frequency factor ($s$). A TL glow curve may consists of more than one TL glow peaks. Many methods had been developed to analyse them including software programming. VHR is one of such methods in which changing $\beta$ alters the TL peaks and, in particular the temperature of maximum intensity ($T_M$). This method can be applied to any order of kinetics [2]. Temperature lag correction is an important consideration in VHR method. The set temperature in TL reader is the temperature of the heating element and not the TL material. Therefore temperature gradient may exist between them and this gradient increases with the increase of heating rate. The TLA is a method to correct this gradient. Several researchers [4,5,6] have done TL characteristic studies for different TL phosphors and polycrystalline CVD diamond. In the present study, TL of natural salt irradiated to 0.5 Gy is analysed by VHR method. The TLA was calculated and corrected for all heating rates used. The physical parameters of corrected and uncorrected values are also compared.
2. Experimental Method
The natural salt Dap Chi (local name), extracted by evaporation of salty river waters of Mizoram, was crushed to fine powder and was pre-heat treated at 110°C for 90 minutes in oven before irradiation. Sample weight \((20 \pm 2)\) mg was used for each measurement. Samples were irradiated from a \(^{60}\)Co gamma ray at a low dose of 0.5 Gy from a TH780C machine with dose rate of 0.0253 Gy/Sec at the time of irradiation. TL measurement of the irradiated samples were carried out immediately after irradiation in a commercial PC based TL reader, model TL1009I photomultiplier tube hamamatsu/ET make Type No. 6095 (Nucleonix System Pvt. Ltd., Hyderabad) operating at 750 volts. Background radiation was also measured and the TL glow curves presented are after background subtraction. The heating rates used were 2, 3, 4 and 5 C/sec with the final temperature set to 300°C. The samples were protected from direct light during the whole process by properly packing in the air-tight black polytetrafluoroethylene.

2.1 Method of Analysis
The dependence of \((T_M)\) on the heating rate \((\beta)\) in VHR method is defined by the following equation.
\[
\ln\left(\frac{T_M^2}{\beta}\right) = E / kT_M + \ln(E / ks) \tag{1}
\]
where \((s^{-1})\) is the frequency factor, \(E\) (eV) is the activation energy, \(k\) is the Boltzmann constant. Hoogenstraten suggested that the plot of \(\ln(T_M^2 / \beta)\) against \(1/kT_M\) is a straight line whose slope gives the activation energy \(E\) and the intercept \(\ln(E/ks)\) gives the frequency factor \(s\). The method is independent of the order of kinetic \(b\) and applicable to any heating rate function \([2]\).

The temperature lag (TLA) between the heating element and the sample can be calculated \([3]\) by the following equation.
\[
T_M^{j} = T_M^{i} - c \ln\left(\frac{\beta_j}{\beta_i}\right) \tag{2}
\]
where \(T_M^j\) and \(T_M^i\) are the maximum temperatures of glow peaks with heating rates \(\beta_j\) and \(\beta_i\) respectively and \(c\) is a constant. This constant \(c\) can be evaluated by using two very low heating rates where TLA is small. In this experiment, heating rates of 2 C/sec and 3 C/sec were used because these heating rates were the lowest heating rates available with the TL reader. The TLA \((\Delta T)\) is given by
\[
\Delta T = T_g - T_M \tag{3}
\]
where \(T_g\) is the peak maximum including the TLA and \(T_M\) is the real glow peak temperature of the same glow peak if TLA does not exist. \(T_M\) is corrected using equations 2 and 3.

3. Results and Discussion
The experimental TL glow curves of natural salt recorded are shown in figure 1. Each experimental glow curve consist of two prominent glow peaks. Only the higher temperature peaks were analysed. The TL peaks shift to higher temperature with the increase of heating rates. The normalized TL response of natural salt integrated from 150-300°C is plotted against heating rates in figure 2. The TLA of all measurements were calculated from equations 2 and 3 and the results are plotted in figure 3. As observed from figure 3, the experimental value of \(T_M\) (curve a) are very high as compared to the corrected values (curve b) as the heating rates become higher. The temperature lag also increases with increasing heating rates. From the figure, it is noted that a TLA of 2.7 K is observed with the heating rate of 277 K/sec.
Thermoluminescence (TL) Response of Natural Salt

Fig. 1: TL glow curves of Natural Salt irradiated with a $^{60}$Co gamma source at different heating rates 2, 3, 4 and 5 C/s

Fig. 2: The normalized TL response of natural salt with respect to low heating rate 2 C/s versus heating rates

Fig. 3: Plot of peaks 2, 3, 4 and 5. Left y-axis: (a) Experimental values $T_{M_k}$ (b) Corrected values $T_{M_k}$ as functions of heating rates. Right y-axis: (c) TLA as a function of heating rate

In the VHR method, the temperature correction is very important because this method is very sensitive to small changes in $T_{M_k}$. In figure 4, a plot of $Ln(T_{M_k}^2 / \beta)$ versus $1/kT_{M_k}$ for both experimental and corrected for the TLA is plotted. This plot should be a straight line with a slope giving the activation energy ($E$), and intercept $ln(E/kT)$ giving the frequency factor ($s$). Table 1 gives these values for with and without TLA corrections. The effect of TLA correction on $E$ and $s$ values as observed from the table showed that if one neglects TLA correction in VHR method then $E$ and $s$ values will be underestimated.

![Graph showing activation energy and frequency factor](image)

Table 1: Activation energy $E$ and frequency factor $s$ values obtained using VHR method

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Without TLA correction</th>
<th>With TLA correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>1.11</td>
<td>1.87</td>
</tr>
<tr>
<td>$s$</td>
<td>$2.41 \times 10^{17}$</td>
<td>$1.76 \times 10^{15}$</td>
</tr>
</tbody>
</table>

4. Conclusion

The variations in the experimental results of kinetic parameters $E$ and $s$ with or without TLA correction showed the need of TLA correction in VHR analysis. It is also confirmed that with the increase of
heating rate the temperature gradient between the heating element and the sample as well as within the sample exist. Decrease in intensity may be attributed to thermal quenching. Thermal Lag Correction (TLA) for all temperatures of maximum intensity (\(T_M\)) were calculated and TLA was found to decrease with increase in \(\beta\). Analysis of TL characteristics suggest that natural salt may be considered for dosimetry applications.

References: