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COMPARATIVE ASSESSMENT OF ENCAPSULATING LENS ON THE LUMEN DEPRECIATION OF HIGH-POWER PC LEDS UNDER TROPICAL CONDITIONS

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In contemporary technological growth, the demand for lighting has increased in indoor as well as outdoor applications. To meet such huge expectations, Light Emitting Diodes (LEDs) are inclining towards energy-efficient illumination. However, the useful life of commercially available LEDs is an important parameter. Gradually over time, depreciation in lumen output of LEDs is observed. There are several factors responsible for such degradation of production. One of the reasons is due to the bulging of the encapsulating lens used on high power PC LEDs. This research discusses the role of encapsulating wafer on LEDs considering the useful lifetime characteristics of high-power PC LEDs. In this, an emerging field that combines physics, materials science, device technology, and industry. We discuss the effect of the lens through systematic observations and calculations are made from the lumen depreciation characteristic graph.

Keywords: High-Power PCLED, LED encapsulating lens, LED reliability, useful life, energy efficiency.

1. Introduction

An Illumination exclusively deliberates light uses to achieve aesthetic needs. Lighting, therefore, plays an imperative role in our day-to-day lives and supposing that more than 80% of our time is used up in indoors, so indoor lighting is a crucial aspect[1]. Now in the present scenario, 30% of domestic, road lighting, industrial, and a hospital's electricity goes towards LED light in our Indian climate zone.

There are four critical technologies behind space lighting today: Incandescent, High-Intensity Discharge, Fluorescent, and LEDs. In core, communication of electrons to photons by using various materials are done using these technologies. Incandescent lights use tungsten filaments, HIDs (High-Intensity Discharge) create superheated plasma light, fluorescents use mercury vapor, and a phosphor coating for lighting and LEDs was make of semiconductor materials[2]. The heating effect of the filament of an electric incandescent lamp due to current flex, excites the atoms of it. It will cause the electrons to jump to a higher energy state. The particles rapidly want to come back to the lower energy state, emitting the excess energy as photons as it is a volatile state. But if it an inert noble gas surround it as, otherwise, on exposed to air, it would burn up fast. (e.g., helium, neon, argon, krypton, xenon, and radon) within the glass made container.

2. Important Parameter for Measuring Useful Life of Led

"Useful life" is the measure of time after which LED lumen percentage degrade below the acceptable lumen level (L70 AND L50)[3]. There are various lumen depreciation reasons. Details will discuss in the below part.

2.1. *Degradation Approach*

The main degradation conditions are dislocations that affect the inner region of the device, metal diffusion and alloy reaction affecting electrodes, soldering instability to degrade the material bonding parts, separation of metals in the heat sink, and defects in buried heterostructure devices. These modes ware enhanced through current during ambient temperature operations. The damage caused on the upper surface due to oxidation is increased by light or moisture content in the tropical Indian climate.

2.2. *Standard Methodology*

Specific parameters ware used to measure the "useful life" of LEDs. These are LM-79, LM-80, and LM-81[4,5]. LM-79 testing measures performance characteristics of products which feature Solid-State Lighting (SSL) technology, which includes LEDs (light-emitting diodes). An Electrical and Photometric test, as stated by IESNA (Illuminating Engineering Society of North America) LM-79 test standard is widely used in illumination. LEDs performance, testing provides us idea under specific operating condition. "Useful life"[5] of a LED, usually at the beginning of the operation; for LEDs, the method was used for initial measurements of the performance.

It does not represent lifetime ratings, lumen maintenance, or LED case temperatures. The LM-79 method applies to several LED products, such as luminaries and lamp replacement. It does not include applicable to LED modules, packages, or arrays. We can make product comparisons using LM-79 data; LM-79 allows for evaluation, which is relative to performance requirements, and is required for voluntary labeling LEDs such as ENERGY STAR® and LED Lighting Facts.

The LM-80 is also another luminary standard. LM-80 is a method to measure the lumen depreciation of solid-state lighting sources, such as LED modules, packages, and LED arrays. Before the discovery of the LM-80 process, LED company manufacturers reported lumen maintenance data using their different method and various systems which were not unique. Avoid the confusion of the customers, members of the IESNA and Philips Lumileds came together to create a new standard method, LM-80, to evaluate and compare the lumen maintenance of LED components for different companies (e.g., Philips, Havells, etc.). To analyze the performance of LED products, LM-80 can be an advantageous method for lighting researchers or lighting professionals, but we cannot measure LED reliability from this method. It only describes under certain conditions, how to measure the specific one part of an LED luminaries, and how the LED light source performs over a specified period. LM-80 is merely one vital part of a giant puzzle. To make a full pictorial view of an LED luminary useful lifetime, we should consider the other components such as LED drivers, heat sink, and LED optical system.

2.3. *Degradation Parameter Calculation Arrangements*

2.3.1. *IES TM-21-11 Approach:*

Lumen Maintenance of LED Light Sources in the long term is predictable through IES TM-21-11[6]. As per IES, this is a lumen lifetime estimation standard. This delivers a method to resolve the LED luminaries functioning life (lumen output declines to average percent, 50% or 70%, of the initial production over a certain length of functioned time) based on the data collected for lumen maintenance from IES LM-80-08[6].

The main application procedure of the IES TM-21-11[6] method provided by TM-21 working group[6] is as follows:

(1) Selecting the sample size. The minimum size of the sample recommended as 20. The lumen maintenance data are collected, which is on the IES LM-80-08 test standard.

(2) Preprocessing the lumen maintenance data. First of all, for each unit, the initial data is removed (0 ~ 1000 h) to reduce the noise, which in the other form we can say encapsulant decay; and then all data to 1 at the time is normalized to zero test point. The next step is to average all the data from at each test point (usually, additional measurements ware taken after the early 1000 hours at intervals smaller than 1000 hours as the fitting data.)

(3) Fitting of the model. Previous work on the HPWLEDs indicated that its deterioration of lumen performance followed the exponential curve[7,8]. LED exponential lumen degradation path model (1) is applied to fit the averaged degradation data using the nonlinear least squares (NLS) method.

$$D(t) = \alpha \cdot \exp(-\beta \cdot t) \qquad (1)^{8}$$

Where D(t) is the averaged normalized luminous flux at time t, α is initial constant, and β is the degradation rate, which varies from unit to unit.

(4) Designing the lumen maintenance life Lp,

$$Lp = \ln((100\times\alpha)/p)/\beta \qquad (2)$$

Where p is the maintained average percentage of the initial lumen output (i.e., 50, 70) of the data.

2.3.2. *DDDM Approach:*

DDDM used ware based on the general degradation path model proposed by Lu and Meeker[9]. ‘n’ was taken as a random sample. The measurement times are t_1, t_2, t_3…..., t_s under the general degradation path model. ‘y_{ij}’ was assigned the performance measurement for i th unit at the j th test time. Hence, the time performance measurement pairs (t_{i1}, y_{i1}), (t_{i2}, y_{i2}), ..., (t_{imi}, y_{imi}), for i = 1, 2, ..., n can be registered the degradation path and mi representing the test time points of each unit,

$$y_{ij} = D\,(t_{ij};\, \alpha;\, \beta_i) + \varepsilon_{ij} \qquad (3)^9$$

where D (t_{ij}; α; β_i) is the actual deterioration path of unit i at the exact measurement time t_{ij} , α is the vector of fixed effects which remain constant for each unit. β_i is a vector of random effects that vary according to the distinct material properties of the different units and their production processes or handling conditions. ε_{ij} represents the measurement errors for the unit i at the time tij, now a normal distribution with zero mean and constant variance, ε_{ij} ~ Normal (0, $\delta\varepsilon_2$) to be as expected.

$$F\,(t) = P\,(t \le T) = P\,[\,D\,(t_{ij},\, \alpha,\, \beta_i) \ge D_f]$$

Time to Failure, $$T = \inf\,(t \ge 0;\, D(t_{ij}\,,\, \alpha,\, \beta_i) \ge D_f\,) \qquad (4)$$

The decreasing type of performance measurement,

$$F\,(t) = P\,(t \le T) = P\,[D\,(t_{ij},\, \alpha,\, \beta_i) \le D_f]$$

Time to Failure, $$T = \inf\,(t \ge 0;\, D(t_{ij}\,,\, \alpha,\, \beta_i) \le D_f\,) \qquad (5)$$

To estimate the time to failure circulation, F(t), which based on the degradation data. Researchers have proposed several statistical methods. They include the approximation method, the analytical method, the two-stage method, and others[10] from these methods that two necessary steps are involved: (a) assessment of the parameters for degradation path model (b) interpreting the time to failure distributions.

3. Research Device Details

In our experiment, commercially available LED is one type of High Power White PCLED

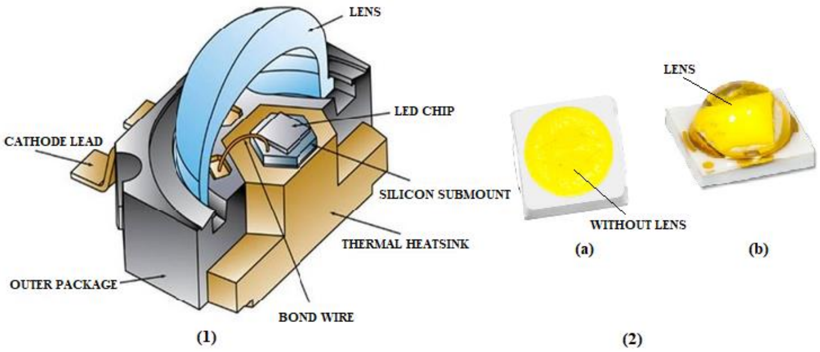


Figure 1. (1) White PCLED and Its Structure. (2) Commercially available High-Power White PC LED:(a) Without lens and (b) With lens

with high luminous flux (>90 lumens in cool white at 350mA) and with Chip-on-Board packaging techniques. From the cross-section of the LED device, in figure 1, (1) is shown the packaging structure. In figure 1, (2), demonstrated the original picture of the high-power white PC LED (a) Shown as without encapsulating lens, and figure (b) is with encapsulating lens. For our proposed experimental, we are using two sets of different types of commercially available 5-watt high power PCLED. Initially, all LEDs are high luminous flux (>90 lumens) with cool white at 350mA.

4. Proposed Experimental Methodology

Four commercially (two different types of commercially) available 5-watt white PCLED Chip-on-Board connected in series are put into "lifetime test" to evaluate "useful life"[5] as per IESNA LM-79 standard[10] as shown in figure 2. Here, we have four 5-watt LEDs; two of them are without encapsulating lens, and others are with encapsulating lens. We ware regularly measure the Lux using the standard Lux Meter. From the result, we get the useful lifetime characteristics of those high power white PCLEDs. From figure 2, the top one is LED_1, then LED_2, LED_3, and LED_4, respectively. LED_1 and LED_3 are with encapsulation, but collected from different placed and similarly, for LED_2 and LED_4 is without encapsulation, again collected from a diverse set. For using the standard test instrument, initially, their specifications are seen in table 1.

Table 1. 5-watt PCLED Specification as IES LM-80-08 Test Condition.

LED Name	LM-80-08 test Temperature (℃)	Input Current (mA)	Ambient Temperature (℃)	Body Temperature (℃)	Relative Humidity (%)
LED_1	55	350	34	62.1	73
LED_2	55	350	34	62.3	73
LED_3	57.5	350	34	60.4	73
LED_4	57.5	350	34	60.4	73

A medium-size chamber which is made by tin, consisting of four hollows, has been used to regulate the "useful life" of these four commercially available 5-watt white LEDs. The size of the box is 24 inch×6 inch×12 inch (length × width × height). The inside of the box is colored deep black to emphasize the light source with full intensity to the standard Lux Meter, which processes the light intensity in Lux. Avoided the chamber reflection of white light, we use block color. Also, look for repelling the light passing to outside through the box.

Each bulb has fitted on the bottom of the box in the middle of each chamber. The 5-watt white LEDs are always on the burning phase with a constant voltage of 14.04 Volt to measure the "useful lifetime." We will see whether there is any effect of encapsulating lens on those LEDs.

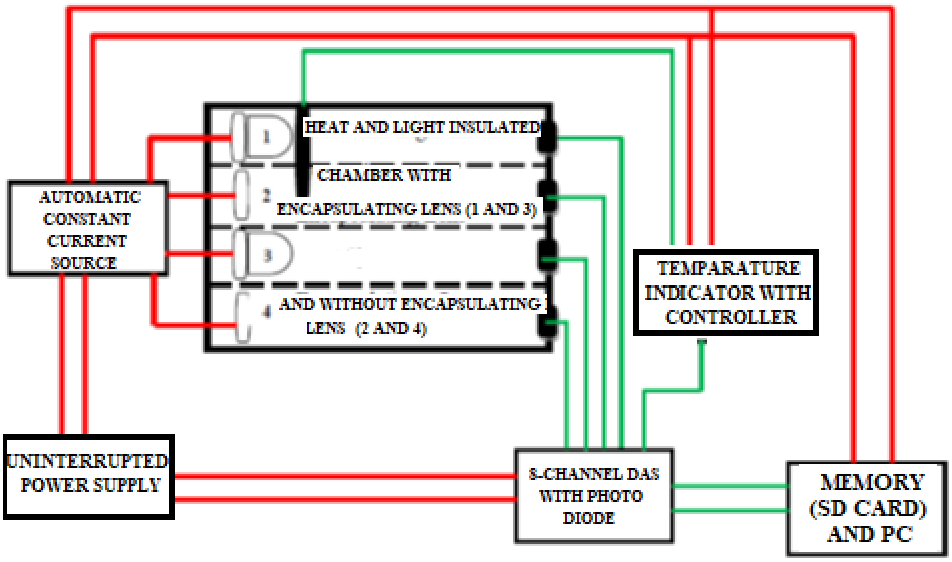


Figure 2. Experimental Setup

5. Result Obtained and Discussion

Lumen output in the first 1000 hours remains almost constant, and duration termed as the seasoning period. The lumen depreciation plots are being extrapolated here up to 6000 hours by adding a trend line in them, showing a future estimation of LED light degradation level over a long time.

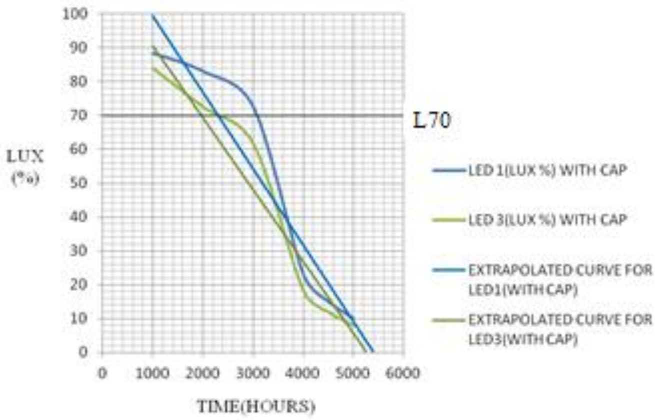


Figure 3. The extrapolated plot of Normalized Lumen level (%) for with encapsulating lens of LEDs

Initially, from 1000 hours (seasoning period of LEDs), both encapsulating lens LEDs do not show much degradation in Lumen output. The output equivalent to 70% (as shaded by the green color of table 2), as shown in figure 3, of the minimum usable Lumen for Lighting purpose, was considered as the initial value.

Table 2: Lumen Percentage Degradation Chart

Hours	Led1 (With Lens) Lumen (%)	Led2 (Without Lens) Lumen (%)	Led 3 (With Lens) Lumen (%)	Led 4 (Without Lens) Lumen (%)
1000	88.42	86.45	84.04	77.17
2000	83.1	86.40	72.6	72.82
3000	72.6	73.9	61.7	66.30
4000	23	24.4	18.3	20.20
4500	15	16.1	12	13.3
5000	10	12	8	9

LED_1 degrades to 70% of output in 3123 hours, whereas LED_3 in 2347 hours (as previously mentioned, the different sets of commercially available PCLED). As time progresses, both LEDs output degrade to about 10% in the output after 5000 hours. So, comparatively LED 1 shows a better light level of acceptance through its burning hours than LED 3.

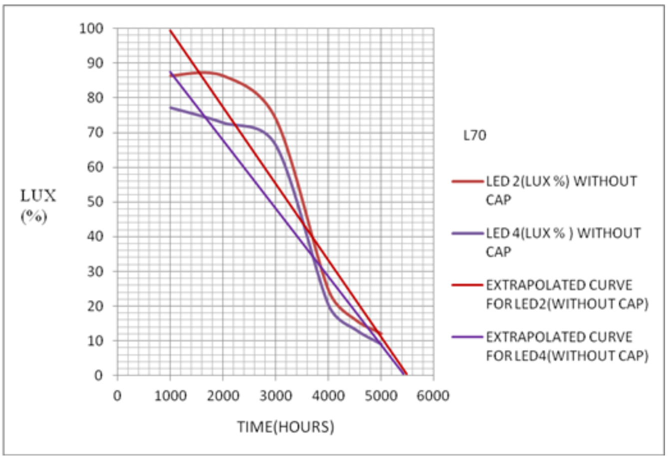


Figure 4. The extrapolated plot of Normalized Lumen level (%) for without encapsulating lens of LEDs

LED_2 and LED_4 (as previously mention, again, a different set of commercially available PCLED) used here are both without encapsulation. LED_2 degrades to 70% of output in 3175 hours, whereas LED_4 in 2853 hours. As time progresses, both LEDs output degrade to about 10% in the output after 5000 hours. Hence, comparatively, LED_2 shows better output than LED_4. There exists an absolute difference in lumen percentage between encapsulating lens LEDs and without encapsulating lens LEDs. After 4500 hours of constant burning, the difference of lumen percentage between LED_1 and LED_2 is 1.1%, and the contrast of lumen percentage between LED_3 and LED_4 is 1.3%. So, we can conclude that without lens LEDs give more lumen that encapsulated LEDs.

6. Estimated Parameters to Analyze Degradation of LEDs

LED exponential lumen degradation path model is applied to analyze the average degradation data using the nonlinear method[12]. The equation used is,

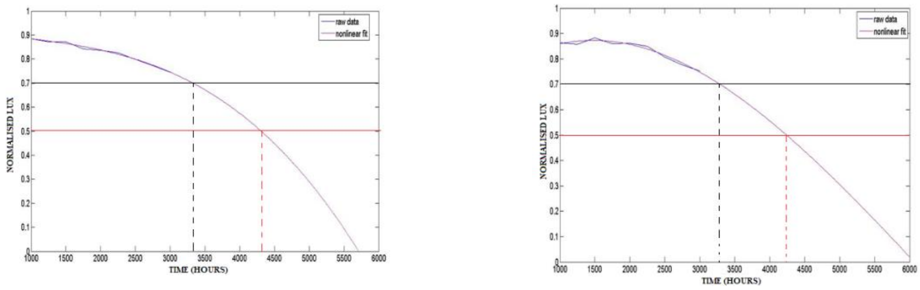
$$D(t) = \alpha . \exp(-\beta . t) \quad (6)$$[9]

Where D (t) is the averaged normalized luminous flux at time t, α is initial constant, and β is the degradation rate, which varies depending on the unit.

Curve fitting is a method of constructing a curve or mathematical function that has the best fit to a series of data points—fitted curves as an aid for data visualization.

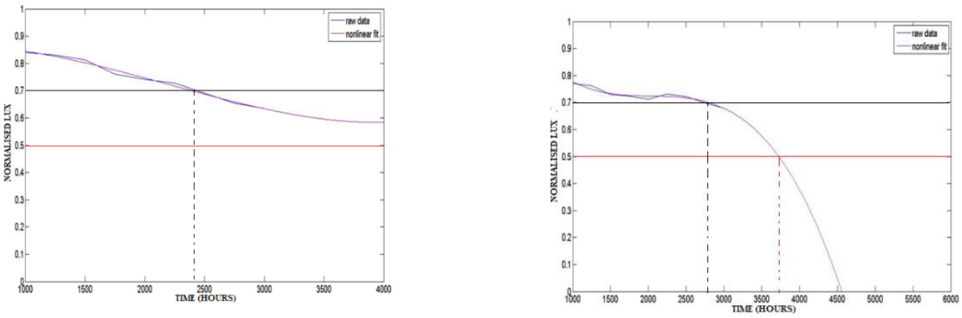
Table 3: Estimated Parameters for Degradation Path Model

Sample No.	Hour	LED 1		LED 2		LED 3		LED 4	
		A	β	α	β	α	β	α	β
1	1000	.999	4.93E(-04)	1.0006	5.84E(-04)	1.0002	6.97E(-04)	1	1.04E(-03)
2	1250	1.0003	5.43E(-04)	1.0006	6.12E(-04)	1.0005	7.40E(-04)	1	1.08E(-03)
3	1500	1.0003	5.43E(-04)	1	5.02E(-04)	1	8.28E(-04)	1.006	1.26E(-03)
4	1750	.999	6.83E(-04)	1.0003	6.03E(-04)	1.0069	1.09E(-03)	1.005	1.29E(-03)
5	2000	1.0008	7.11E(-04)	1.0006	5.98E(-04)	1.0073	1.19E(-03)	.9988	1.36E(-03)
6	2250	1.0008	7.64E(-04)	1	6.5E(-04)	1.0041	1.27E(-03)	.997	1.24E(-03)
7	2500	1.0004	9.02E(-04)	1.0004	8.52E(-04)	1.0029	1.48E(-03)	1.0002	1.297E(-03)
8	2750	1.0096	1.02E(-03)	1.0007	1.016E(-03)	1.0014	1.69E(-03)	1	1.438E(-03)
9	3000	1.0017	1.17E(-03)	1.0003	1.134E(-03)	1.0015	1.82E(-03)	1.0002	1.56E(-03)



(a) (b)

Figure 5A. (a)With Encapsulating Lens of LED_1 for linear curve fit (b) Without Encapsulating Lens of LED_2 Lumen Depreciation Curve for linear curve fit.



(c) (d)

Figure 5B. (c) With Encapsulating Lens of LED_3 for linear curve fit and (d) Without Encapsulating Lens of LED_4 Lumen Depreciation Curve for the linear curve fit

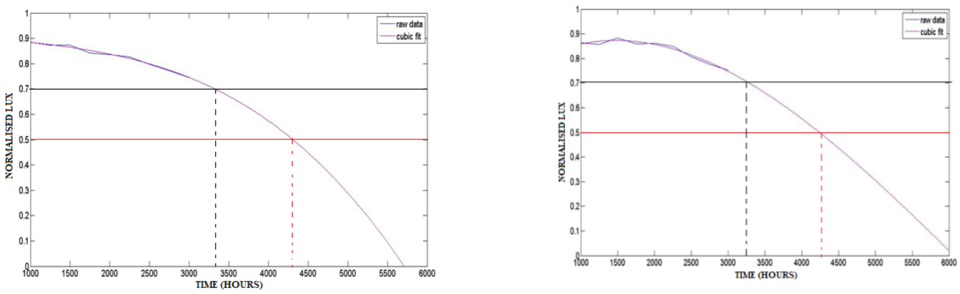
6.1. *Cubic Fit*

Let try to fit a cubic polynomial to some data. We randomly generate a set of data points to be provided to a cubic. Here we ware estimated the useful life of 70% and 50% of different types of white Power PC LED. At first, we are trying to Cubic fit the graph. Here we use MATLAB software to fit the graph.

$$y = P_1*x^3 + P_2*x^2 + P_3*x + P_4 \quad (7)$$

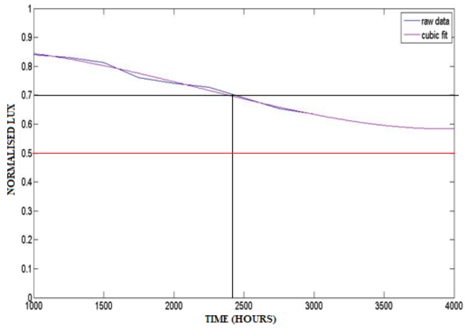
Table 4: Estimated Parameters for Degradation Path Model for Cubic Fit

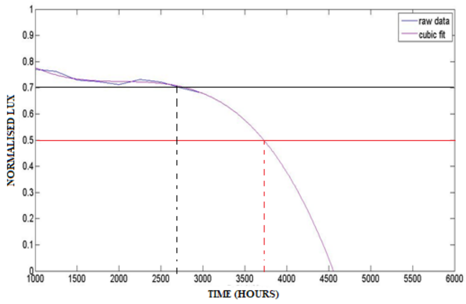
LED	P_1	P_2	P_3	P_4	No. of Residuals
LED_1	-5.6027E (-12)	1.0776E(-08)	-3.9674E (-05)	0.91869	0.014154
LED_2	4.0673E(-12)	-7.8075E-(08)	0.00020386	0.72902	0.024453
LED_3	1.3145E(-11)	-8.6644E (-08)	7.0409E(-05)	0.84728	0.023777
LED_4	-4.3852E (-11)	2.667E(-07)	-0.00054615	1.1005	0.023221



(a) (b)

Figure 6A. (a)With Encapsulation of LED_1 and (b) Without Encapsulation of LED_2





(c) (d)

Figure 6B. (c) With Encapsulation of LED_3 and (d) Without Encapsulation of LED_4 Lumen Depreciation Curve for Cubic Fit

6.2. *Quadratic Fit*

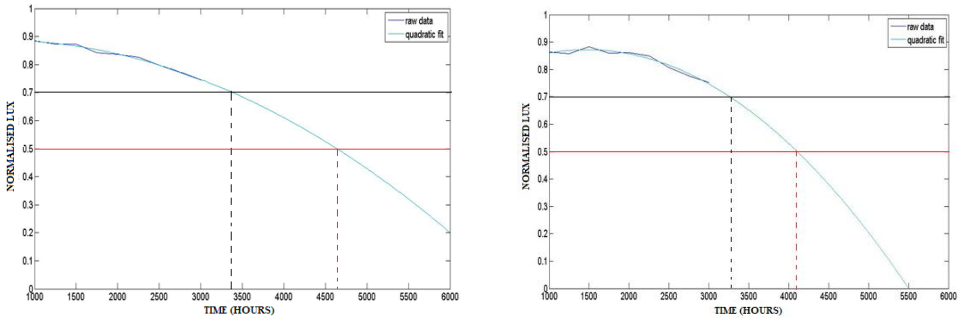
A quadratic regression is a method of finding the equation of the parabola that best fits a set of data. A quadratic function is a second-degree polynomial.

Now we are trying to Quadratic fit the graph. Here we use MATLAB software to fit the graph.

$$y = P_1*x^2 + P_2*x + P_3 \tag{8}$$

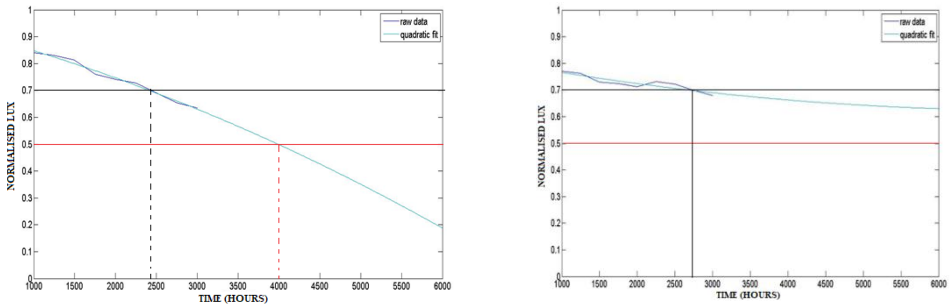
Table 5: Estimated Parameters for Degradation Path Model for Quadratic Fit

LED	P_1	P_2	P_3	Norm of Residuals
LED_1	-2.284E (-08)	2.3426E(-05)	0.88214	0.014535
LED_2	-5.3671E (-08)	0.00015805	0.75556	0.02457
LED_3	-7.7749E (-09)	-7.7634E (-05)	0.93305	0.02501
LED_4	3.5844E(-09)	-5.2271E (-05)	0.81438	0.034764



(a) (b)

Figure 7A. (a)With Encapsulation of LED_1 and (b) Without Encapsulation of LED_2



(c) (d)

Figure 7B. (c) With Encapsulation of LED_3 and (d) Without Encapsulation of LED_4 Lumen Depreciation Curve for Quadratic Fit

6.3. *Gaussian Fit*

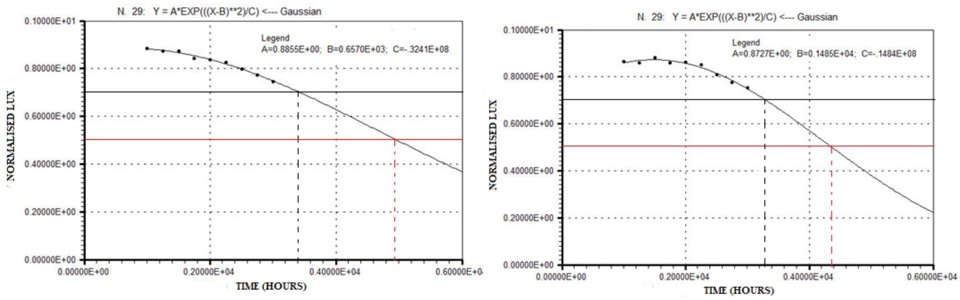
Fitting gaussian shaped data does not require an optimization routine. Just calculating the moments of the distribution is sufficient, and this is much faster.

Now we are trying to Gaussian fit the graph. Here we use MATLAB software to fit the graph.

$$y=a*\exp(((x-b)^2)/c) \quad (9)$$

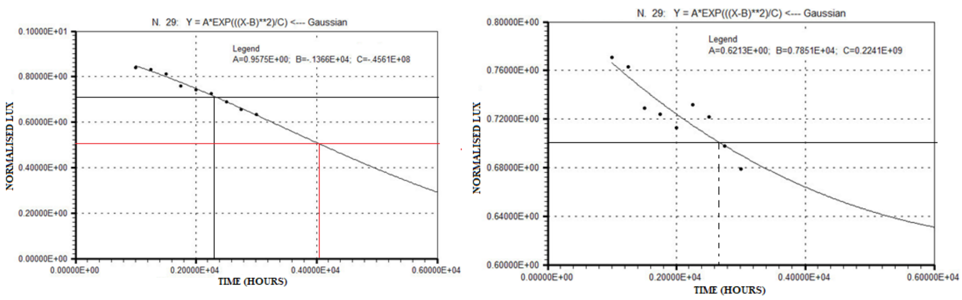
Table 6: Estimated Parameters for Degradation Path Model for Gaussian Fit

LEDs	A	B	C
LED_1	0.8855	0.6570×10^3	-0.3241×10^8
LED_2	0.8727	0.1485×10^4	-0.1484×10^8
LED_3	0.9575	-0.1366×10^4	-0.4561×10^8
LED_4	0.6213	0.7851×10^4	0.2241×10^9



(a) (b)

Figure 8A. (a)With Encapsulation of LED_1 and (b) Without Encapsulation of LED_2



(c) (d)

Figure 8B.(c) With Encapsulation of LED_3 and (d) Without Encapsulation of LED_4 Lumen Depreciation Curve for Gaussian Fit

In general, the Gaussian equation is Y=A*EXP(((X-B) ^2)/C). Here Y is Normalized Lux along Y-axis, and X is Hour along X-axis. Now we consider the main degradation parameter is A. So, from the change of the value of A, we say whether with lens LEDs or without Lens LEDs degrade more. The difference in the value of A between LED_1 and LED_2 is 0.0128, and the contrast of the value of A between LED_3 and LED_4 is 0.3362. From table number 7, we see in LED_1 and LED_3 the value of the degradation parameter is more compared to the value of the degradation parameter of LED_2 and LED_ 4. So, from the value of the degradation parameter, we can easily say with lens LEDs degrade more than without lens LEDs.

Table 7: Estimated Comparison for L70 Parameter Degradation Path Model

L70 LEVEL(HOURS)					
LED	Cubic Fit	Quadratic Fit	Gaussian Fit	Linear Fit	Average Fit
LED_1(WITH LENS)	3350	3405	3500	3600	3463
LED_2 (WITHOUT LENS)	3250	3350	3300	4350	3562
LED_3(WITH LENS)	2400	2400	2400	2400	2400
LED_4 (WITHOUT LENS)	2750	2750	2750	2800	2762

The difference in the value of A between LED_1 and LED_2 is 0.0128, and the contrast of the value of A between LED_3 and LED_4 is 0.3362. In LED_1 and LED_3, the value of the degradation parameter is more compared to the value of the degradation parameter of LED_2 and LED_4. Moreover, without encapsulation, LEDs give more lumen than encapsulated LEDs. From the value of degradation parameter, the LEDs with lens degrade more than those without the lens. Thus, in conclusion, LEDs without encapsulation give more lumen than encapsulated LEDs.

Table 8: Estimated Comparison for L50 Parameter Degradation Path Model

L50 LEVEL [Hours] (Extrapolate Result)					
LED	Cubic Fit	Quadratic Fit	Gaussian Fit	Linear Fit	Average Fit
LED_1(WITH LENS)	4301	4545	4856	4320	4505
LED_2 (WITHOUT LENS)	4353	4350	4875	4460	4509
LED_3(WITH LENS)	<4700	4010	4101	<4500	4327
LED_4 (WITHOUT LENS)	3778	<6000	< 6500	3756	5008

From our experiment, we can see that lens has an essential role in the LED lumen percentage degradation. From the beginning of our research, we see LED_4 gives low Lux than other LEDs. Here we see a specific difference in lumen percentage between encapsulating lens LEDs and without encapsulating lens LEDs from the above table 7 and 8. After 4500 hours of constant burning, the difference of lumen percentage between LED_1 and LED_2 is 1.1%, and the contrast of lumen percentage between LED_3 and LED_4 is 1.3%. So, we can conclude that without lens LEDs give more lumen that encapsulated LEDs.

7. Conclusion

Here in our experiment, we find that without the encapsulating lens of LEDs, give more lumen than with encapsulating lens of LEDs (two different sets of commercially available

5-watt white PCLED). We used four commercially (two sets of different types of commercially) available 5-watt white PCLED for our experiment. Here at the end of 4500 hours, we see that the Lux of LED_1(a different set of commercially available, which similar set of LED_2) is 15 and the Lux of LED_3 (a different set of commercially available, which the same set of LED_4) is 12. LED_1 and LED_3 are with encapsulate LED, but when we see them without encapsulation LEDs, then the result is for LED2 that is 16.1 and for LED_4, that is 13.3. Further study can be done with these LEDs to see the effect of encapsulation on LEDs more prominently. So, we can say that encapsulation affects LED lumen percentage. For sophisticated application, ware used L70 (mention in table 6), as our observation. For some low-end and domestic purposes also ware used L70 to L50 (mention in table 6) life of LED.

From our result, we can easily say that without lens LEDs give more lumen than encapsulated LEDs.

In this working model, “useful life” of 5-watt white LEDs, as well as their thermal performance, have been studied for a time of 4500 hours, lumen depreciation characteristics are plotted & extrapolated the data up to 6000 hours[1,2]. Future work is carried for extended periods such as 10000 hours or 12000 hours to extrapolate the graph more conspicuously. Junction temperature, degradation of semiconductor material with an increase in the number of cracks, can be carried yellowing of the epoxy encapsulation for the LEDs. Future work can carry out to measure the decrease in transmissivity and aging of the lens. With heat, there is a degradation of the lens. It turns yellowish and expected that there is a change in the refractive index, which could be measured to estimate the lumen degradation.

In this paper, the useful life was determined of commercially available 5-watt white PCLED by DDDM, and other curve fitting approximation method, the analytical method, and those obtained when using the IES TM-21-11 method ware compared the estimation results.

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