PHOTOLUMINESCENT STRUCTURES: A TRUE EXPERIMENTAL STUDY INTO LUMINOUS FLUX EFFICIENCY AND VIABILITY

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ABSTRACT

Photoluminescence structure is a concept that has existed for decades. The idea that a single structure could emit natural light without the need for electricity, dangerous emittance of temperature or radiation has enticed engineers. The phosphor ZnS:Ag or Silver- Activated Zinc Sulfide is known for its brilliant blue hue during photoexcitation. This generates a bright and sustained emission of light without the need of electricity. As the reaction is not caused by direct heat or a reaction due to ignition or explosion, it is not considered phosphorescent in nature. But rather photoluminescent. This is mainly because the process, photoexcitation, causes light photons to be absorbed by the molecular structure of the atoms. Known to be stable and highly efficient as a semiconductor, the light emitted by the reaction is bright blue as silver is its activator. In order to determine the efficiency, luminous flux (lx), a derived unit of measurement from lumens (lm), in which it too is derived from the base SI Unit- Candela (cd) is used. One lx is equivalent to one lm per square meter. Over time, the efficiency can be determined. Additionally testing for Viability (V) is determined by three sub-variables, namely V1-lm or Light observed on objects, V2-t, or luminescence endurance, and V3E-lm or Environmental luminescence. Combined they are used to determine the viability of the phosphor in physical applications as a replacement to traditional light sources such as CFL, LED, or Incandescent. The light is measured through photometry and not photo-spectroscopy. This involves the use of a photometer rather than a spectrometer. This is done because the test sample is not quartz-cubed and would require a laser-based spectrometer. To simplify and receive similar results with respect to the instrument, a photometer is used instead. The collected data is originally determined in Lux but is converted into the needed data. After following a stringent testing protocol, the data is tabulated, analyzed, and graphed. The data was found to show a trend in decreasing luminosity count in relation with time. As time increased, luminosity decreased. This is expected as the phosphor gradually loses its photons to emit, and thus light is slowly reduced to undetectable units. Additionally, the length of time it took for the luminosity of the phosphor to become undetectable was surprisingly high. Averaging seven to eight hours at maximum peak brightness of 3.9 lux.

Keywords: Photoluminescence, Photometry, Luminosity, Luminous Flux (lx), Lumens (lm), and Silver-Activated Zinc-Sulfide (ZnS:Ag)

INTRODUCTION

In 2014, the city government of Manila implemented a P2.2 billion project to discharge 10,000 solar-powered streetlamps to decrease the energy consumption of the local government (Sauler, E., 2014). Solar streetlights are appraised as result of a Study on the Efficiency of Solar lights in Intramuros (Claridad et al., 2017) wherein it was delineated as the easiest way to conduct light with its dependence on a natural source of power which is solar energy, through photovoltaic panels, and its low maintenance of keeping the material workable and feasible. However, with the reason for its immoderate prices and costs, it will be resistant to be established nationwide due to a foundationless local government in regard to energy supply. According to the Journal of Energy and Power Engineering (Billanes et al., 2017), the Philippines is included as one of the countries with the highest paying rate of electricity as a result of importing fuel from other countries and not owning a stable energy supplier nationwide. As already stated, the Philippine Government does not supply the costs of electricity. The Department of Energy (DOE) responded that supporting the electric status of the Philippines will only lead to vague and bureaucratic actions and decisions (Rood, 2015).

In those factors, the city government of Manila executed a project to elevate the standard of the city and conceivably solve the issues. However, as per the International Energy Agency (2002), solar-powered streetlights can be hazardous to nearby environments for it can be easily activated by other toxic compounds even if indirectly. Compounds such as cadmium telluride that is a part of the solar panel, when inhaled causes lung inflammation, and lung fibrosis (Nguyen, 2017). Even if it is powered by a natural source of energy - sunlight there are still cons that cause uncertainty to execute the project nationwide. Since 1990, the energy crisis is one of the major problems of the Philippines that cannot be solved that easily if there would be no alternative to modern light sources that brightens up the surroundings yet prolongs the high electricity consumption of the country.

The perpetuating energy crisis would only be an additional factor in pulling the government down. It has been three decades of letting the crisis enter the country yet there is no concrete solution to reduce it. Thus, in relation, there are still other light sources that Filipinos can benefit from. Photoluminescence also emits light in any form of matter ensued from the absorption of Photons. Thus, relating it to artificial light sources existing in Manila, it can also be utilized in discharging light in structure based. It will be investigated and experimented with the support of a Photolumic Phosphor - Zinc Sulfide activated with Silver (ZnS:Ag) to test the luminous flux and viability of a structure coated with Photoluminescent. By knowing that there are existing modern and fixed streetlights in Manila, finding an alternative source of light that is neither attached nor electrical would be very beneficial to the city in different aspects and could be applicable nationwide. A Photoluminescent structure could be an effective substitute to traditional street lights or any other artificial light source, thus the question, What is the impact of the Photoluminescent Coating (ZnS:Ag) on luminous flux (lx) efficiency, light spread in lumens (lm), and viability (V)?

Literature Review

According to Gfroerer (2000), Photoluminescence (PL) is the spontaneous emission of light from a material under optical excitation. Additionally, Photoluminescence (PL) is observed to last longer than Phospholuminecence under excitation that is caused by ultraviolet-ray exposure rather than chemical reaction which is shorter and generally brighter (Caper et.al. 2017). As for the selected photolumic phosphor, “Zinc sulfide (ZnS) activated with Ag (Silver) ions is known for its brilliant blue luminescence under excitation with high energy photons, electrons or ions.” (Mikhailik et. al., 2012). However, “Fluorescence and phosphorescence are particular cases of luminescence. The mode of excitation is absorption of one or more photons, which brings the absorbing species into an electronic excited state. The spontaneous emission of photons accompanying de-excitation is then called photoluminescence which is one of the possible physical effects resulting from interaction of light with matter.” (Valeur, 2013). Additionally, according to Valeur and Santos (2011; Valeur, 2017), “In contrast to phosphorescence, the etymology of the term fluorescence is not at all obvious. It is indeed strange, at first sight, that this term contains fluor which is not remarked by its fluorescence!” The definitions of fluorescence and phosphorescence, as given in the Glossary of Terms used in Photochemistry published by the International Union of Pure and Applied Chemistry (1926; Valeur, 2017), are as follows: Fluorescence: spontaneous emission of radiation (luminescence) from an excited molecular entity with retention of spin multiplicity. Phosphorescence: phenomenological, is a term used to describe long - lived luminescence. In mechanistic photochemistry, the term designates luminescence involving change in spin multiplicity, typically from triplet to singlet or vice versa. Alternatives according to Depika, Kaaviya, Kavitha, & Indhumathi (2019), a pigment that has the ability to produce light in a dark environment is said to be photo luminescent. Strontium Aluminate doped with rare alkaline earth elements from the lanthanide series, primarily Europium and Dysprosium, is proven to absorb radiant light energy and slowly release it as glow in the absence of the light source. Hence Strontium Aluminate doped with Europium and Dysprosium activators was adopted to achieve brighter afterglow in the concrete. Thus, Luminescence flux (lx) efficiency of ZnS:Ag is required to be investigated. According to Derlofske & Taylor (2000), Luminescence Flux (lx) is a SI-derived unit of another SI-derived unit- Lumens (lm) that originates from Candela (cd). As One lx is equal to one lm/m2 (Area). Thus, luminous flux efficiency of ZnS:Ag, a Photoluminescent phosphor has not been investigated to date, thus the conduction of this true experimental study by the researchers.

As per Caper et.al. (2017), Lumens (lm) is a photometric (light) SI-Derived unit for Candela (cd) used in measuring the total quantity of visible light emitted by a source per unit of time. The basic setup for measuring luminous intensity involves a light detector located a certain distance in front of a point source. Its numerical response, 'n', depends on the impingement rate (flux) and wavelength of photons. The detector's spectral sensitivity matches that of the human eye. This enables the detector's response to be calibrated to indicate lumens (luminous flux). (Nilson, 2009). Avoidable light pollution refers to light flow emitted at night by artificial light sources which are inappropriate in intensity, direction and/or spectral range, unnecessary to carry out the function they are intended for, or when artificial lighting is used in particular sites, such as observatories, natural areas or sensitive landscapes. Among all causes having a negative effect on night sky quality, light pollution shows the highest immediate risks but, at the same time, it can be reduced through viable solutions. (Rajkhowa, 2012). According to Gaston, Bennie & Hopkins (2014), artificial lighting has transformed the outdoor nighttime environment over large areas, modifying natural cycles of light in terms of timing, wavelength, and distribution. This has had widespread benefits and costs to humankind, impacting on health and wellbeing, vehicle accidents, crime, energy consumption and carbon emissions, aesthetics, and wildlife and ecosystems. Light scatter (in Lumens) has been often avoided as a parameter for viability. However, if scaled, could lead to increased parametric viability, thus the added investigation into the matter.

According to Dipika et.al. (2019), Viability (V) is determined by a subset of pre-attached variables that justify viability for implementation in a particular field of interest i.e. construction, medicine, engineering, etc. From these considerations re-emerge the ideas of Peccei (2013) and King (2013) that recognize in the systemic thought the foundations for a sustainable society. The present study derives from these considerations and aims at contributing to the advancement of the knowledge necessary to overcome the challenges in the sustainability field." (Formisano, Quattrociocchi, Fedele, 2018). The principal analytical tool of viability theory is the viability kernel which describes the set of all state-space points in a constrained system starting from which it is possible to remain within the system's constraints indefinitely. (Krawczyk & Pharo, 2013). Financially, a clear economic rationale for public sector involvement helps to narrow the range of alternative ways of addressing a development problem. Public intervention is justified when a market fails to deliver goods and services efficiently. Market failures can arise from various factors such as increasing returns to scale, externalities, asymmetric information, unspecified property rights, coordination failures, and specific characteristics of certain public goods that make their use nonrival and nonexcludable. (Asian Development Bank, 2017). Additionally, as added note on its sub-variables, Ecological light pollution comprises direct glare, chronically increased illumination and temporary, unexpected fluctuations in lighting. The sources of ecological light pollution are very various and found in nearly every ecosystem in the form of sky glow, illuminated buildings and towers, streetlights, fishing boats, security lights, lights on vehicles, flares on offshore oil platforms, and even lights on undersea research vessels. (Rajkhowa, 2012). It is important to note that parametric viability (V) on ZnS:Ag for probable implementation on public-use structures has not been explored to date, and is in relation to luminous flux efficiency and light scatter, thus the need for investigation.

The researchers draw importance on the Theory of Luminescence by Stepanov & Gribkovskii (1968) and from Valeur's Molecular Fluorescence Principles and Applications (2013) to determine the impact of ZnS:Ag, a Photoluminescent Coating, on luminous flux (lx) efficiency, light spread (scatter) in lumens (lm), and viability (V) for real world implementation on man-made structures. According to Taylor (2000), the theory of luminescence was created when a faint glow emanating from a rotting tree bark was discovered and observed in the early 1800s. Since then, the theory has expounded on luminosity valence and various conjectures have been formed on their origin, synthesis, and possible real-world application." As for Valeur (2017), the theory was the beginning of scientific and grounded exploration into biochemical photosynthesis that created illumination from absorption of photomater (visible light) which ultimately led to the advancements in research of phosphors and their various outputs. In relation to this investigation, Photoluminescence has been the topic of modern construction sciences for decades. Yet much is still unknown about their viability. Additionally, combination of various aggregates into a phosphoric chemical mixture can hamper the overall effectivity of such a product. The researchers do note however that this could have been more applicable as an additional layer in construction rather than integration into a singular product.

To justify, Valeur's Molecular Fluorescence Principles and Applications (2013) adds additional importance and justification on the basis of Stepanov & Gribkovskii's work. As per Spunei & Chioncel (2017), the adaptation of the theory of luminescence and phosphors paved the way to electroluminescence that is essential to the creation of more powerful semiconductors used in most electronics today. Additionally, the theory laid the foundations for powerful superconductors that operate at specific conditions that can hold immense amounts of power for long periods of time without risk of forming Dendrites and other traditional alternatives like Li-po (Lithium-Polymer) or NiMH (Nickel-Metal Hydride) batteries. To that effect, the study into luminosity flux efficiency and viability of the phosphor ZnS:Ag is warranted as there have been no previous attempts to do so, thus the conduction of this investigation.

Hypotheses

A. A higher luminous flux count (lx) generates a brighter glow per square meter.

B. A brighter luminous flux count (lx) leads to increased light spread detected on objects in Lumens (lm).

C. (V1-lm), (V2-t), and (V3E-lm) contributes to greater viability (V).

METHODOLOGY

The study was conducted in order to determine the luminous flux (lx) efficiency and viability of the photoluminescent phosphor ZnS:Ag. Specifically the study aims to identify the viability of ZnS:Ag for possible application in man-made structures as an alternative to traditional street-lighting systems such as CFLs or LED technology that doesn't require the use of electricity. The researchers have selected a true-experiment design in conducting the study. It allows for the researchers to manipulate and control their testing samples or test groups in order to determine or understand processes based on pre-existing parameters set. Because of the control granted by the design, the researchers can now determine the luminous flux efficiency and viability of ZnS:Ag that ultimately answers the research questions. The testing methodology allows for full control and contingency-plans that enable the researchers to further conduct with little to no influence from outside forces, the result of the experiments to be conducted. Additionally, as the research is required to be quantitative in nature, social methodologies are thus minimized or outright forbidden. This is further justified as mathematical and scientific data alongside the use of inferential statistics to be the sole source of observed/tested data in concluding the study conducted. As aforementioned, the research, although true-experimental in nature, will follow a parametric-based testing regime to answer each individual sub question leading to the main overall question of the study. This will be reflected under the conclusion of the study.

The study contains three main phases of experimentation as specified by the research questions. The first phase involves the determination of luminous flux efficiency (lx) by direct testing through a Photo/Luxmeter. The second phase involves the empirical observation of light scatter in lumens (lm) by the photoluminescent light source. And lastly, the third phase involves the sub-testing of various parameters such as viability of surrounding lit-objects (V1-lm), visibility of luminescence endurance (V2-t), and viability of environmental luminescence (V3E-lm). Please do note that the visibility of luminescence endurance (V2-t) is taken into account in order to determine the maximum viable length of time the product is visibly observed to produce (emit) light.

Materials

The testing procedures are based on the original testing methodologies by Stepanov & Gribkovskii however modernized and adapted to fit the current research requirements. The use of a photometer in order to determine the luminous flux efficiency of ZnS:Ag as well as its viability for implementation on man-made structures was first determined by a study conducted by Rajkhowa from Lund University. The 1:25th scale ratio was determined to be the most scientifically accurate as it was compared to area-based testing rather than volumetric-based testing. The total amount of ZnS:Ag (Silver Activated- Zinc Sulfide) is 310g (± 5g) with the activator. This is because only 2 layers will be added overall to the testing platform. The thickness of each layer according to past studies is about 22.7 nanometers. With two layers combined, that totals to 45.4 nanometers. It will be applied through an application scalpel typically used for painting. An allowance of 2 hours is given for the phosphor to adhere to the surface. It is then attached with a thin layer of polyacrylate that is proportional but single layer only to the ZnS:Ag phosphor. This is to secure the phosphor and protect it from outside influence.

The Diorama (Test Platform)

The diorama will be the main testing platform for the phosphor ZnS:Ag to be applied. It is designed to limit the amount of light entering the experimental system through enclosement. A triage of monitoring systems such as cameras and the photometer will monitor the light emitted within the enclosed system. Additionally, only sunlight (natural-sourced) will be used for comparison as any other source would be detrimental to the significance of the study determined to begin with. This is known as an "Outside-Source Secured System or OSS" for experimental testing. The cameras nor the photometers to be installed generate alien light.

Luminous Flux Efficiency (lx)

The researchers are testing for efficiency and not efficacy, the implementation of luminous flux (lx) which equates to 1 lumen (lm) per square meter was selected. With efficiency tested in light produced per square meter of area within the test platform. It is important to mention that Luminous Flux (lx) is an SI-Derived Unit that originates from Lumens (lm) in which Lumens is then derived from Candela (cd)- an SI Base Unit. The main testing apparatus used to determine such is an Argus 5000 pro-series Lux/Photometer. Approved by EOL, it is capable of testing luminous flux, lumens, and offers conversions to other SI/SI-Derived Unit for light or luminosity. Additionally, it has a built-in data logger capable of 10000 entries at 1 second intervals. This is measured from a distance of 10 cm from the test platform. A total of 3 trials are required, the average is the final result.

Parametric Viability (V)

The testing regime for Parametric Viability or simply stated as Viability is unique to the research as it aims to address multiple concerns by sub-testing. These are as aforementioned: viability of surrounding lit-objects (V1-lm), visibility of luminescence endurance (V2-t), and viability of environmental luminescence (V3E-lm).

Surrounding Lit-Objects (V1-lm)

The viability of surrounding lit-objects or stated as V1-lm aims to identify if the product is capable of lighting up surrounding objects because of the unknowns associated with the light scattering nature of the phosphor Zns:Ag. This will be done through placing test objects at various lengths within a closed and controlled system in order to determine the amount of light visibly observed. This is measured in lumens and measured from a distance of 10 cm from the test platform or area of interest. A total of 3 trials is required, the average is the final result.

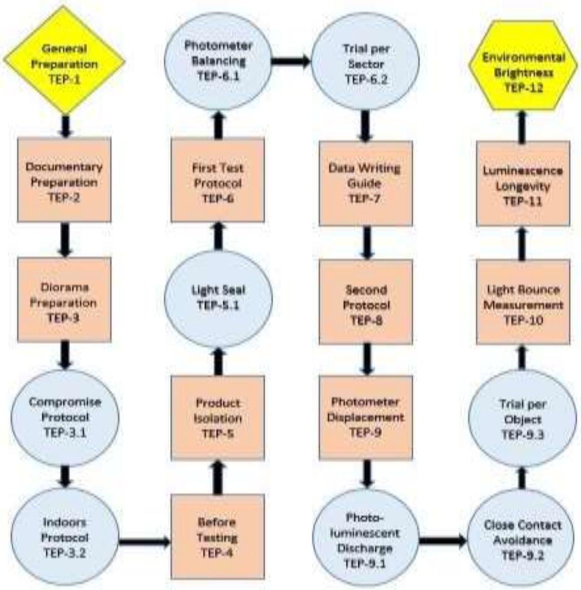
Luminescence Endurance (V2-t)

The second test is for visibility of luminescence endurance, stated as V2-t. The aim of this test is to determine how long the luminescence of ZnS:Ag lasts under photoexcitation. The test will require the product to absorb natural light for 5 continuous hours. After absorbing, the product is then enclosed once more, and the sensors take over. The sensor will be directed to measure the light source in real time as it slowly fades. A digital timer is attached and is monitored by the attached cameras. After the lumen count drops beneath "1" the product is considered as "no longer generating visible light" and the timer is thus stopped. This is measured in the following format as "Hours: Minutes: Seconds (00:00:00:000)". A total of 3 trials is required, the average is the final result. It is important to note that for the sake of visual illustrations, all times collected is converted into seconds.

Environmental Luminescence (V3E-lm)

Lastly, the third test is viability of environmental luminescence or stated as V3E-lm. The aim of this test is to determine if the light produced by the product is greater than the light produced by natural elements such as Moonlight, or Light reflected from laminated surfaces. For obvious reasons, Sun light is not taken into account as currently, Sunlight is more powerful than any source of light for public use. The test will require the use of artificial lighting to excite the ZnS:Ag phosphor, after which, the test will be done open in a clear night sky with sensors measuring the data every 1 second. This is automatically logged. The data is then averaged for the final result. This is also measured in lumens. This is measured from 32cm or 12 inches from the test platform or area of interest. A total of 3 trials is required, the average is the final result.

Flowchart of True-Experimental Tests (TEPs)



The simplified flowchart details a clear path of the testing procedures with contingencies in the event of failure or compromise. The rhombus marks the start of the experimental procedures, and the Hexagon for the end of the experimental phase. The square shape denotes main procedures with the circles denoting sub-procedures or contingency plans.

RESULTS AND DISCUSSION

The following data displayed are raw. These are used to explain the trend visible on the graphs. For the first test, the data is recorded in Lux. But do take note that 1 Lux= 1lx (Luminous Flux). 1lx= 1 lm/m2. A conversion is thus not required, and the data can be interpreted directly. To eliminate possible disparities, a total of 173 data points were recorded (Only 163 is displayed here). And these were recorded over 30 second intervals. These total at 5,160 Seconds (±60 Seconds) of testing or approximately 86 Minutes (±1 Minute). Only the average is displayed here. The average deviation of the data is less than 1%, accuracy is thus at 99% scientific.

Table 1: Luminous Flux Testing Data (lx) in Lux

Cross Average 1	Cross Average 2	Cross Average 3	Cross Average 4	Cross Average 5	Cross Average 6	Cross Average 7
3.633333333	3.466666667	3.4	3.2	2.833333333	2.3	1.933333333
3.6	3.433333333	3.4	3.1	2.733333333	2.3	1.933333333
3.666666667	3.466666667	3.4	3.066666667	2.766666667	2.333333333	1.866666667
3.7	3.466666667	3.366666667	3.066666667	2.733333333	2.266666667	1.8
3.666666667	3.466666667	3.333333333	3.033333333	2.7	2.266666667	1.866666667
3.7	3.4	3.333333333	3.033333333	2.633333333	2.233333333	1.933333333
3.666666667	3.4	3.366666667	3.033333333	2.633333333	2.166666667	1.8
3.7	3.333333333	3.3	3	2.7	2.2	1.8
3.7	3.533333333	3.3	3.033333333	2.666666667	2.233333333	1.733333333
3.666666667	3.366666667	3.333333333	3	2.6	2.166666667	1.766666667
3.666666667	3.3	3.333333333	3	2.666666667	2.1	1.733333333
3.666666667	3.333333333	3.3	3	2.6	2.066666667	1.633333333
3.633333333	3.366666667	3.333333333	2.966666667	2.6	2.133333333	1.633333333
3.633333333	3.3	3.266666667	3	2.7	2.1	1.633333333
3.633333333	3.266666667	3.266666667	2.933333333	2.566666667	2.1	1.6
3.5	3.266666667	3.3	2.9	2.5	2.066666667	1.633333333
3.5	3.266666667	3.266666667	2.833333333	2.466666667	2.033333333	1.5
3.433333333	3.366666667	3.266666667	2.866666667	2.466666667	2.033333333	1.5
3.466666667	3.333333333	3.266666667	2.9	2.5	2	1.433333333
3.466666667	3.366666667	3.3	2.866666667	2.4	1.966666667	1.4
3.466666667	3.366666667	3.233333333	2.833333333	2.433333333	1.966666667	1.366666667
3.5	3.333333333	3.2	2.833333333	2.4	1.966666667	1.333333333
3.466666667	3.4	3.166666667	2.833333333	2.333333333	1.933333333	1.266666667

Average Deviation: 0.63072 (<1%)

Graphed Test Results

To understand the data simpler for this test. The graph below shows a decreasing curve. This is because as time goes on, the luminosity flux or lux count of each interval decreases. Now although gradual, the rate of change is not constant and is varied. This could be due to multiple factors such as particle reflection, photo sensor recalibration, and even the photoexcitation process itself. However, it is clear that the light emitted decreases over time, and this is expected by the researchers. Do note that cross average between each individual test is used in this regard to simplify the huge data set recorded.

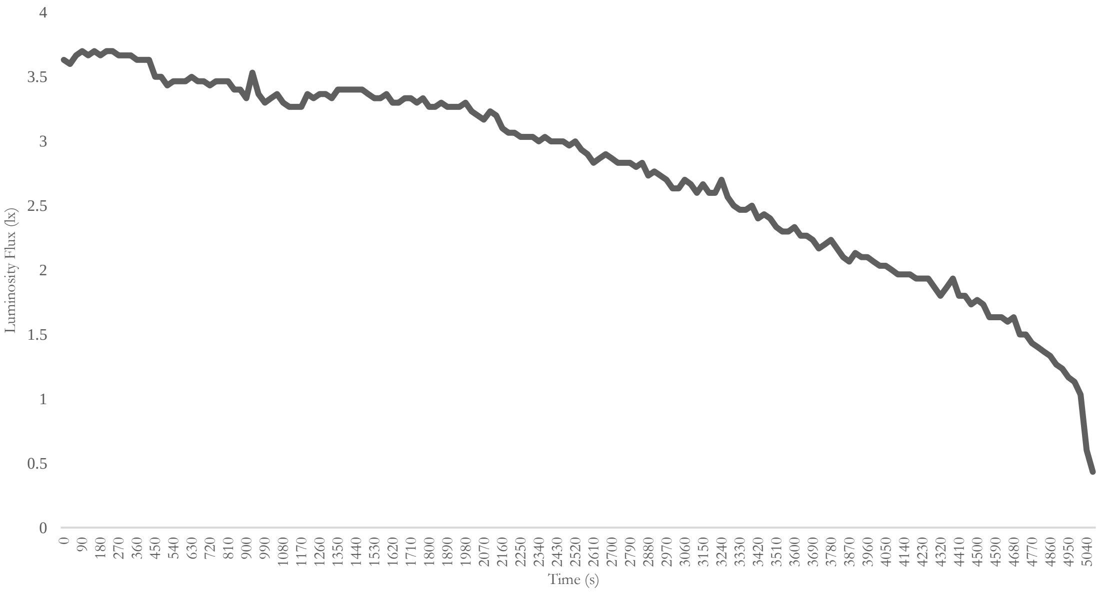


Figure 1. Luminosity Flux (lx) Cross Average Efficiency Curve over Time

In test 2, the following data has been collected. Do note that the data presented herein is recorded using a digital stopwatch. The computer is programmed to automatically stop the recording time if the detection of light or Lux of the photometer falls below 0.5. This is because a lumen/Lux count of 0.5 and below is no longer considered viable (observable) light. This was discussed by Gribkovskii in the theory of luminescence. Additionally, a total of 16 data sets were recorded (cross average). Note that it is recorded in seconds and only 11 sets are displayed.

Table 2. Viability (V2-t): Luminosity Endurance (t) Testing Data in Seconds

Trial 1	Trial 2	Trial 3	Cross Average
26901	27198	28110	27403
28102	28172	28182	28152
28212	26721	23998	26310.33333
25920	27281	28912	27371
28192	27812	28917	28307
26625	29002	27165	27597.33333
27821	28172	28192	28061.66667
25245	28918	27165	27109.33333
27821	28172	27514	27835.66667
23256	28812	27221	26429.66667
24526	29001	27219	26915.33333

Average Deviation: 723.141 seconds (12.05 Minutes). (<5%)

Unlike other phosphors, ZnS:Ag uses a highly stable structure. This stable structure allows for as little photons as possible to escape. Which means, during photoexcitation, as photons of light enter the chemical structure, they remain as such as the phosphor or photon decays over time due to the loss of energy. As light is energy or heat, ZnS:Ag was able to absorb as much as it could, given the molecular available spacing, it slowly emits than vice versa. Additionally, the data is almost uniform in nature, which is why the phosphor is believed to be the best compound for this experimentation.

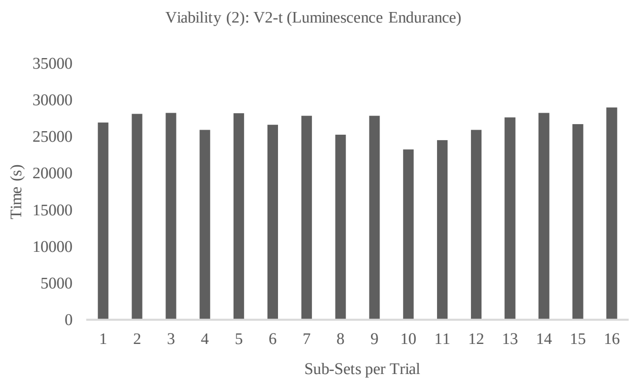


Figure 2. Viability (V2-t): Luminosity Endurance (t) trial 1

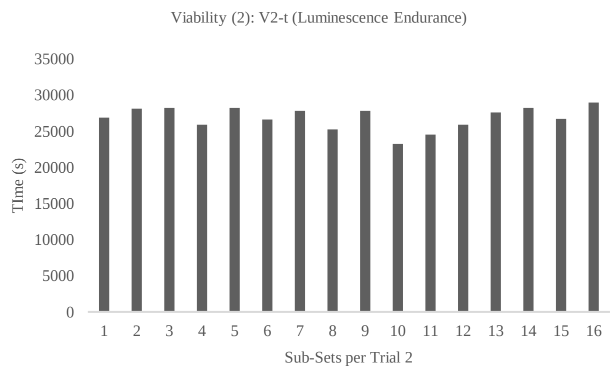


Figure 3. Viability (V2-t): Luminosity Endurance (t) trial 2

The final experimental test result shown herein is the Light Observed on Objects (V1-lm) viability. Now why is this important? For starters, it denotes that light emitted by the phosphor is bounced, reflected, absorbed by the surrounding area, or object of interest. Do note that there are a total of 21 data sets. However only 15 is displayed for simplicity. It is recorded in almost the same manner as the 1st test. The only difference is that the photometer was distanced just <10mm from the object for increased resolution. Do note the specific object associated with the data. The cross average is used as a basis for discussion.

Table 3: Viability (V1-lm): Light Observed in other Objects in Lux

Object of Interest (OIs)	Trial 1	Trial 2	Trial 3	Cross Ave
Model Car	3.92	4.01	3.89	3.94
Model Boat	3.82	3.81	3.76	3.797
Model Tree	3.57	3.56	3.91	3.68
Model Bike	3.89	3.78	3.22	3.63
Non-glass Window (Cellophane)	4.91	4.22	4.84	4.657
Water Reflection (Cellophane)	4.76	4.48	4.65	4.63
White Wall (Cardboard)	4.782	4.66	4.02	4.487
Model Grass (Foam)	3.92	3.88	3.77	3.857
Model Car (2)- With Reflectors	3.781	3.672	3.879	3.777
Model Car (3)- Black Colored	3.12	3.18	3.42	3.24
Black Wall (Cardboard)	2.48	2.38	2.08	2.313
White Wall with Black Patterns	3.88	3.76	3.69	3.777
White Wall with Reflectors	4.21	4.03	3.99	4.077
Model Table/Bench Black	2.32	2.37	2.88	2.523
Model Lantern with Glass Housing	9.12	8.74	7.922	8.594

Average Deviation: 0.79905 Lux. (<15%)

Unlike the previous tests, this test is easily understandable. Before explaining further, it is important to state that these are models. Results may vary in real life or full scale models due to use of different materials, quality of such materials, and/or natural decay or dilapidation. To explain, the researchers would like to take the water reflection, white wall, and model lantern with glass housing to compare. The water reflection was made possible due to the use of cellophane, a plastic that dissolves easily with water. This is used to simulate the effects of water with intended ripples; thus the placement is not smooth or even flat. To enhance the water effect, a dark blue sheet was placed beneath the cellophane layer. Compared to the white wall, the data is almost negligible in difference. This is because both bounce light rather than absorb and as the bounced light hits the photo sensor of the test instrument, it artificially inflates the results. But what happened with the model lantern? The model lantern has a built-in glass housing. Due to the angle of the glass elements, it created an artificial crystalline effect and reflected the light as well as amplified it. This was a data point worth mentioning because the results are almost 3x higher than other tested objects of similar nature.

Another question that popped up. Why is there no test for V3E-lm? During the time of testing, quarantine protocols were still in effect. This made setting up of any testing installation outdoors in communities, discouraged or outright banned. However, thanks to the data collected from the first luminous flux test, an artificial simulation of what it would be when outdoors was conducted. The researchers realized that by doing so, the light source was simply not strong enough to fight out the natural light of the moon which peaked at 12.7 lux. Now, a higher concentrate of the compound could fix this result. But as for viability, the product fails in this regard. It is important to note that more research on this phenomenon is required to further justify its findings.

CONCLUSION AND RECOMMENDATION

The study was mostly successful in determining the viability and efficiency of ZnS:Ag (Silver-Activated Zinc-Sulfide) as a potential electricity-free alternative to traditional lighting sources. To summarize, the data was significant in regard to its hypotheses and has exceeded or met expectations with high accuracy and a low margin of error. Additionally, overall deviations in data sets were acceptable and are considered true-experimental. With more of the world becoming dependent on these potentially dangerous and hazardous lighting sources, it becomes a clear cause for worry. Even more so now, as we come to the 21st year of this century. Now the world has made great strides in restructuring its energy generation sources, diversifying their means of doing so, and seeking new innovative technologies that go beyond the boundaries of proven and theoretical sciences. But unless we start from the very first technologies that used electricity- i.e.: the light bulb, we are putting those efforts at waste. As far as the experimentations conducted, the data was glaring. It showed the potential for these phosphors to be used as safe and sustainable alternatives to traditional lighting sources. Over a large distance, photo excited by the sun, these have the possibility of lighting up entire cities without a drop of electricity usage. Which is fairly important for modern day, developing countries like the Philippines.

With that said, these are the following recommendations that the researchers would like to mention.

- The need for laser-based spectroscopy is essential for determining the luminous distance physically, rather than through luminous flux. Because although the conversion is 1:1, it doesn't take into account air molecules, air humidity, and/or specific light waves such as infrared, and ultraviolet spectrums.
- The need for more accurate photometers is important. Although with a maximum resolution of 100,000 Lux, the photo sensors' resolution rate at distance is poor. With a tangible 15% drop off in resolution per millimeter. This creates inaccuracies when viewed through the data gathered and is not recommended.
- The use of more realistic models is a recommendation as the models used were either made of plastic or die-cast materials such as silica, polyurethane, and polystyrene.
- An air-tight or vacuum chamber, to determine if light emitted is influenced by air molecules in a controlled experimental environment with relation to its Lux count or radiance.

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