Use of Light Source Encapsulation in IECEx/ATEX Zone 1 Hazardous Locations

Abstract

Explosive gas atmospheres present specific risks from ignition caused by electrical component operation and failure. Products used in these applications must offer protective features to insure isolation of potential ignition sources from unstable environmental materials. For lighting applications within zones that experience intermittent exposure to explosive gas atmospheres, prescriptive codes and standards have been established to insure these systems operate in a safe manner.

Lighting products present a challenge in combining requirements for protection with efficient light emission. Lighting products inherently contain components that emit heat at surface temperatures within the ignition range of many gases, and electrical components that could, in catastrophic failure modes, create arcing that could act as an ignition source. To address these concerns, in Zone 1 environments, two primary protection concepts are applicable to lighting products; flameproofing and intrinsic safety (which includes encapsulation). Flameproof is a construction in which any ignition or explosive reaction is contained and extinguished within a luminaire. Encapsulation is a construction that eliminates the intrusion and contact between flammable gasses and live components (electronics and light sources), eliminating the potential for catastrophic failure. Encapsulation then reduces the remainder of the product's protection concept under increased safety standards.

Lighting products produce light using one of four primary methods: hot filament sources, such as halogen and incandescent lamps, which present very high internal and lamp surface temperatures; low pressure gas discharge, in the form of fluorescent sources, which contain heating elements and electrical medium voltage arc streams that are utilized to create visible light; high pressure gas discharge, in the form of HID sources (High Pressure Sodium, Pulse Start Metal Halide, Metal Halide and Mercury Vaport), that present extremely high surface and component temperatures and high voltage arc streams that are utilized to create visible light, and; solid state technology, specifically LED sources, which convert low voltage current to light directly, with moderate surface temperatures. Due to the intrinsic nature of filament and gas discharge sources, thermal characteristics, and their need to be serviced frequently (lamp replacements required between 750 and 20,000 hours), the only possible protection concept available for luminaires using these sources is flameproofing to protect operators and facilities from failure through containment of any potential ignition that might occur from contact between flammable gases and light source components.

Solid-state technology, with the advent of LED light sources, presents an opportunity to utilize encapsulation. LED light sources contain no pressurized gas, nor do they employ hot filaments or arc sources. The construction of LED sources, which includes packaging that encapsulates the LED die (actual light source) under a layer of silicone material containing materials for blue light conversion, already isolate the highest energy points within them from the atmosphere. Solid-state electronic components are frequently encapsulated to isolate internal components from external environmental conditions. LED light sources are also well suited to encapsulation, including optical components. Further, LED sources deliver exceptionally long service lifetimes, eliminating the need to open luminaires for service, facilitating full encapsulation of sources, optics and supporting electronic and electrical components.

Introduction

This paper explores the differences in hazardous exposure protection methods between conventional light sources and solid-state technology, with a review of code requirements and Zone 1 equivalencies that are applicable. Aspects of damage resulting from interaction of light source ignition sources and flammable gaseous materials, and the maintenance, reliability implications of the protection concepts employed are presented, as they apply to the design, application and continuous service.

This paper also compares the optical and energy utilization of light sources, and the effects of protection concepts, including flameproof and encapsulated product approaches on product performance initially and over the service life of products.

Background

Hazardous location electrical codes and standards throughout the world are defined by two distinct paths. In North America, a “Class, Division” system is used as the basis for area classification of hazardous (classified) locations. In other parts of the world, explosive atmospheres are addressed through a “Zone” system based on the International Electrotechnical Commission (IEC) and European Committee for Electrotechnical Standardization (CENELEC) standards.

IECEx/ATEX[(1)] (ATEX is derived from the French title of the 94/9/EC directive *‘Appareils destinés à être utilisés en **AT**mosphères **EX**plosibles’*) requirements are defined by two directives. For equipment, ATEX 95, directive 94/9/EC (manufactured prior to April 2016) and 2014/34/EU Article 44 (manufactured after April 2016) defines product requirements, while ATEX 137, directive 99/92EC addresses minimum requirements for workplace safety. The most significant component of IECEx/ATEX directives is that the level of hazard probability is divided into three Zones (See Table 1.0).

In the United States and Canada, methods of protecting electrical equipment for different material exposures and hazardous locations are divided into three Classes, and two Divisions. The Classes reflect the type of hazard and the explosive characteristics of the material, while the Divisions reflect the risk of fire or explosion. With a few small differences, these two countries employ similar protection methods and product standards. While specific requirements differ, the Unites States and Canada have incorporated a similar Zone System for Class I hazardous locations in recent electrical code updates (see Table 2.0 and 4.0). Both systems provide effective solutions for protection used in hazardous locations.

For the purposes of this paper, the focus is on IECEx/ATEX Zone 1 (which generally includes subsequent coverage of North American Class I, Division 1, and Class I, Zone 1) in defining approaches to equipment protection methodology for hazardous locations in which flammable or explosive gases are likely to be present, either continuously, or intermittently (Table 1.0).

Standards within IECEx/ATEX Zone 1 include specifications for equipment protection concepts within three divisions related to Equipment Protection Level (EPL), (ATEX 1G, 2G, and 3G, corresponding to IECEx EPL Ga, Gb and Gc), which are then included in defining the protection concept utilized (see Table 3.0).

Table 1.0 – Classification Systems by Frequency of Exposure Occurrence

Frequency of Occurrence	North American Class I Division System	IECEx/ATEX Zone System
Hazardous gas, vapor or mist		
Continuous – Where an explosive atmosphere consisting of air and dangerous substances in the form of gas, vapor or mist is present continuously or for long periods.	Class I, Division 1	Zone 0
Intermittent - Where an explosive atmosphere consisting of air and dangerous substances in the form of gas, vapor or mist is likely to occur in normal operation occasionally.		Zone 1
Abnormal Condition - Where an explosive atmosphere consisting of air and dangerous substances in the form of gas, vapor or mist is not likely to occur in normal operation or for a short period only.	Class I, Division 2	Zone 2

Table 2.0 Hazardous Area Definition[(2)]

ATEX equipment group	ATEX equipment category and environment type	Zone classification ATEX/IECEx	Required equipment protection level (EPL)	Class/Zone classification (North America)	Class/Division classification (North America)
II	1G (Very High)	Zone 0	Ga	Class I, Zone 0	Class I, Division 1
	2G (High)	Zone 1	Gb	Class I, Zone 1	
	3G (Normal)	Zone 2	Gc	Class I, Zone 2	Class I, Division 2

Table 3.0 ATEX/IECEx Protection Concepts

Typical Electrical Equipment Exposed to Flammable Gases, Vapors and Mist

Symbol	Type of protection	Basic concept of protection	Suitable for Zones			Typical EPL			EN/IEC Standard
			0	1	2	Ga	Gb	Gc	
eb	Increased safety	No arcs, sparks or hot surfaces, enclosure IP54 or better		•	•		•		60079-7
d	Flameproof	Containment of the explosion		•	•		•		60079-1
ia	Intrinsic safety	Limitation of spark energy and surface temperatures	•	•	•	•			60079-11
ib				•	•		•		
ic					•			•	
ma	Encapsulation	Keep the flammable substances out		•	•		•		60079-2
mb				•	•		•		
mc					•			•	

Table 4.0 Protection Concepts for North America and Canada

Typical Lighting and Electrical Equipment Exposed to Flammable Gases, Vapors and Mist

U.S. Code	Canadian Code	Type of protection	Basic concept of protection	Class I, Division		Class I, Zone			U.S. Standard	Canadian Standard
				1	2	0	1	2		
AEx e	Ex e	Increased safety	No arcs, sparks or hot surfaces	•			•	•	ISA 60079-7	CSA E60079-7
AEx d	Ex d	Flameproof	Contain the explosion and extinguish the flame	•			•	•	ISA 60079-1/ UL 1203/ FM 3615	CSA 60079-1
AEx ia	EX ia	Intrinsic safety	Limit energy of sparks and surface temperature	•		•	•	•	ISA 60079-11/ FM 3616	CSA E60079-11
AEx ib	EX ib			•			•	•	ISA 60079-15	CSA E60079-15
AEx nL	EX nL	Limited energy	—					•	ISA 60079-15	CSA E60079-11
AEx m	Ex m	Encapsulated	Keep flammable gas out	•			•	•	ISA 60079-18	CSA E60079-18
AEx ma	N/A			•		•	•	•		Not Applicable
AEx mb				•			•	•		

Light Source Technology Factors

Light source technology has a profound effect on protection concepts. Light sources, such as HID, halogen and fluorescent present several challenges to protection from exposure to hazardous gases. Due to short service life, glass lamp technologies require frequent service of spent lamps over the life of a product. Further, internal arc sources and high temperature filaments that exceed the flash point temperatures of all gases within Zone 1 applications, demand complete isolation of the lamp and its surrounding compartment from atmospheric gases present. HID and halogen technologies also produce high temperatures that demand increases in luminaire cavities to reduce surface temperatures. Due to the frequency of access for regular lamp replacement, risks of failure of compartment seals is increased as the product is serviced over its lifetime.

LED technology, due to relatively low surface temperature, and extremely long service life, provides opportunities to incorporate protection methods, such as encapsulation, to reduce exposure risks while significantly reducing the cavities of luminaires themselves. Further, due to the high efficacy of LED sources, the total energy and subsequent related heat, is reduced, presenting lower external luminaire surface temperatures, with significantly smaller luminaire cavities (and subsequent external dimensions).

Table 5.0 illustrates the characteristics of the light source, and how these impact protection approaches.

Table 5.0 Light Source Comparison

Source	Arc hazard	Surface temperature hazard	Luminaire cavity requirement (surface temperature reduction)	Maintenance interval * (hours)	Maintenance access/ failure risk	Potential for encapsulation
Halogen/ Incandescent	Moderate	High	Large	500 – 3,000	High	n/a
Metal Halide	High	Very High	Large	5,000 - 20,000	High	n/a
HPS	High	Very High	Large	5,000 - 30,000	High	n/a
Fluorescent	Moderate	Moderate	Moderate	5,000 - 30,000	High	n/a
LED	None	Low	Small	70,000-100,000	Minimal	Light source and electronics

** Light source maintenance interval based on range of hours to first failure (infant mortality) of source to longest expected full service life expected before maintenance is required to restore product to functional service.*

Solid State Technologies (LED) Impact On Protection Approach

LED light sources present several opportunities to reduce luminaire size and weight. The characteristics of LED light sources and supporting electronic components are particularly well suited to the application of encapsulation to isolate both electrical connections and heat sources from intrusion of gases. Optical encapsulants can also include features that eliminate, or enhance optical performance, reducing product mass and scale, resulting in lower profile designs in compact enclosures. Further, the lower operating temperatures of LED sources allow the use of polymer materials for lenses and optical enclosures.

Encapsulation provides additional advantages in prevention of explosion or damage, application in >55°C (131°F) ambient environments, and provides for common construction beyond Zone 1, including Zone 2 as well as dust exposure Zones 21 and 22.

Encapsulation Approach, Materials, and Design Considerations

Typically, encapsulation of electronic components for LED products is identical to other encapsulated electrical and electronic components, using common potting polymer systems, such as epoxies, silicones, and polyurethanes, which can serve a dual purpose of providing thermal conductivity, or isolation depending on product design requirements.

For optical encapsulation, the use of silicone and siloxane hybrid materials is most common. High quality optically clear encapsulants suited to Zone 1 encapsulation, typically deliver 90% to 95% transmission, with long service life at temperatures up to 200°C (392°F) without yellowing for the service life of the LEDs encapsulated(2). These encapsulants may be used over LED arrays with no other optical components, molded into optical forms to act as lenses and/or diffusers, or around and under discrete silicone, polycarbonate, or Poly(methyl methacrylate) (PMMA) optical components.

Approaches to encapsulation vary between product designs. The most economical approach is to encapsulate electronics and LEDs into luminaire bodies, essentially sealing the interior into a non-serviceable assembly that is permanently sealed. This approach requires the entire luminaire to be replaced at the end of service life. Modular designs utilize individually encapsulated components attached within the housing, that are able to be replaced at the end of service life without necessitating complete luminaire replacement.

In either construction, there remains space within the luminaire that remains un-encapsulated. For this reason, while encapsulation provides additional protection in Zone 1 applications, luminaires utilizing encapsulation or encapsulated modules will also include additional areas within the product covered under other equipment protection levels (EPLs). This includes the cavity not filled with encapsulants, wire connection compartments, and wireways between components that are not otherwise covered. However, the utilization of Ex mb (encapsulation) reduces the requirement of protection of these uncovered cavities from Ex d (Flameproof) to Ex eb (Increased Safety) to fully satisfy the requirements of Zone 1 application. Figure 1.0 below illustrates the combination of EPLs applied to a luminaire that employs encapsulated modules within a Zone 1 design.

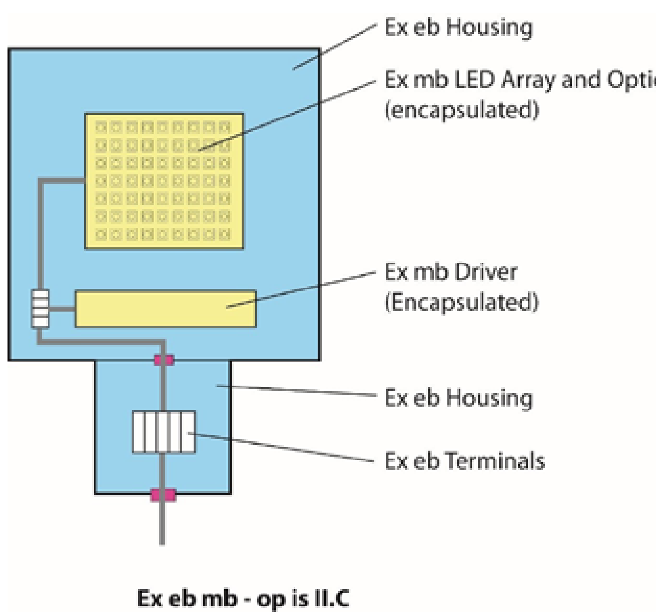

Figure 1.0 – Example Composite Protection Method Diagram

While encapsulation provides additional protection within luminaire construction, which can be used to reduce product size and weight, the connection of the luminaire, and the housing surrounding the encapsulated modules must be considered and designed under eb, or "Increased Safety" protection methods. Encapsulation of components or modules does not replace this requirement.

Luminance Effects and Efficiency

The comparison of total luminaire efficiency between conventional flameproof (Ex d protection method) products (HID, fluorescent and LED) and LED products that utilize encapsulation for additional protection requires consideration of several variables. While large reflectors and high efficiency optics may produce a theoretical advantage over encapsulated products, the advantage is very small, considering that modern encapsulants deliver transmission of >90%. Additionally, integration of optical features into the encapsulant itself, over sealing a molded separate optic onto the LED array with silicone, reduces light loss. This integrated approach produces optical performance that is equivalent to non-encapsulated luminaire designs.

Optical systems for HID sources generally account for greater losses in efficacy than encapsulant materials impart on LED sources, while LED optics (both encapsulated and bonded) tend to be more efficient and suffer less degradation over time due to dirt accumulation, surface degradation due to aging and maintenance contact, and surface area accumulation of debris, scratches, and material degradation.

Additionally, LEDs produce significantly higher efficacy than any other light source. This produces a margin of tolerable loss for application of protection methods, such as encapsulation, to realize gains in luminaire design, reduced scale, streamlining appearance, thermal management, and reducing weight.

Testing Requirements

Testing of encapsulated components within luminaires is no different than any other protection method. All materials utilized in products intended for Zone 1 applications must be fully tested, including employment of HALT (Highly Accelerated Life Test) methods, salt spray testing, as well as quality controls to insure product integrity remains over the intended service life.

While there are no universal or established HALT parameters for testing encapsulated luminaires, the following test parameters could be considered a baseline for establishing product performance under conditional extremes:

1. Strife test: increase ambient until failure (105°C (221°F) or more) (4 hours at each level)
2. Thermal Shock Test: -40°C to 125°C (-40°F to 257°F), 30 minutes each, 250 cycles
3. High Temperature Steady State Test: LED T-case 105C, 1000 hours
4. Low Temperature Steady State Test: -55°C (-67°F), turn on, 500 hours
5. Temperature and Humidity Stress Test: 85°C (185°F), RH: 85%

For products utilizing encapsulation of LED sources within optical systems, additional consideration of adhesion of encapsulants to LED arrays, optical components (where employed), and degradation of optical performance over the service life of the sources utilized, is required. The unique interface of light source components, optics and encapsulant materials, present differences in coefficient of expansion conditions that must be tested over the entire operating temperature and humidity range anticipated for the intended application.

Conclusion

The opportunity to employ the protection concept of encapsulation presented by solid-state technology is a significant improvement over conventional flameproofing, in all areas of product design including physical construction, optical design and energy efficiency, through use of efficient LED light sources over conventional lamps (which cannot be encapsulated), and protection from damage caused by interaction of light sources with flammable materials in Zone 1 applications. Encapsulation delivers Ex mb protection, eliminating the need for flameproof construction, while also providing specific light beam pattern generation, with a resulting increase in total system performance (efficacy and precision of illumination delivery) over a reflector/lamp flameproof fixture.

References

1.) *Directive 2014/34/EU, (ATEX - "Atmosphères explosibles") product directive, applicable from 20 April 2016, replacing the previous Directive 94/9/ EC applicable from 1 July 2003 until 19 April 2016.*

2.) *IEC Classification per IEC 60079-10-1. EU Classification per EN 60079-10-1. US Classification per ANSI/NFPA 70 National Electrical Code (NEC) Article 500 and 505. Canadian Classification per CSAC22.1, Canadian Electrical Code (CEC) Section 18, and Annex J.*

3.) *Dow 'WI-1184 Optical Encapsulant', Form no 11-3508A-01, April 2015.*

United States (Headquarters)
Appleton™ Grp LLC
9377 W. Higgins Road
Rosemont, IL 60018
United States
T +1 800 621 1506

Australia Sales Office
Bayswater, Victoria
T +61 3 9721 0348

Korea Sales Office
Seoul
T +82 2 3483 1555

China Sales Office
Shanghai
T +86 21 3338 7000

Chile Sales Office
Las Condes
T +56 2928 4819

Canada
EGS Electrical Group Canada Ltd.
99 Union Street
Elmira ON, N3B 3L7
Canada
T +1 888 765 2226

Asia Pacific
EGS Private Ltd.
Block 4008, Ang Mo Kio Ave 10,
#04-16 TechPlace 1,
Singapore 569625
T +65 6556 1100

Middle East Sales Office
Dammam, Saudi Arabia
T +966 13 510 3702

India Sales Office
Chennai
T +91 44 3919 7300

Europe
ATX SAS
Espace Industriel Nord
35, rue André Durouchez,
CS 98017
80084 Amiens Cedex 2, France
T +33 3 2254 1390

Latin America
EGS Comercializadora Mexico
S de RL de CV
Calle 10 N°145 Piso 3
Col. San Pedro de los Pinos
Del. Álvaro Obregon
Ciudad de México. 01180
T +52 55 5809 5049

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