THE ADVANTAGES, CHALLENGES, AND CRITICAL ASPECTS TO ACHIEVING ROBUST SEALS WITHIN HAZARDOUS LOCATION ELECTRICAL INSTALLATIONS

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Abstract – Explosion-proof conduit fittings, cable glands and connectors require a seal to limit the passage of flames and flammable gases and vapors. This paper will review currently available sealing technologies within the harsh and hazardous electrical market. Advantages and challenges of the various sealing technologies will be identified based on specific chemistries and environmental effects on sealing compound reliability. Additionally, critical installation best practices necessary to reduce risk and achieve robust and safe seals will be discussed.

Index Terms — Seals, Sealing Compounds, Harsh and Hazardous Location, Installation, Maintenance, Cable Glands, Connectors, Conduit, Conduit Fitting

I. INTRODUCTION

Sealing compounds, also known as potting compounds, are ubiquitous throughout hazardous location electrical systems, demonstrated by numerous manufacturers offering many explosion-proof conduit seal fittings, glands, and connectors, Fig. 1. These sealing systems limit the passage of gases and vapors, as well as prevent the passage of flames. According to National Electric Code (NEC) requirements, most conduit systems require seals within 18 inches of an enclosure, control station, or panel board [1]. Even in Europe and Asia where International Electrotechnical Commission (IEC) regulations are prevalent and where cable installations are preferred over conduit, sealing is required for flameproof cable glands [2]. Additionally, potted seals are used in flame-proof electrical connectors for portable or temporary power distribution common on drilling platforms.

Fig. 1 Examples of conduit seals, cable glands, and connectors requiring seals for explosion proof protection.

These seals are an integral part of the overall protection scheme providing a safe and reliable electrical distribution system in harsh and hazardous locations, Fig 2. Improper selection or installation of a sealing system can compromise the entire system with potentially catastrophic results.

Conduit seals per the NEC are not designed to prevent the migration of liquids, gases or vapors over time [1]. Wherever the potential for a pressure differential exists, specifically designed terminations such as Type MI cable should be used to prevent the migration of liquid, gases or vapors. These seals are outside the scope of this paper and have been the topic of previous PCIC papers [3][4].

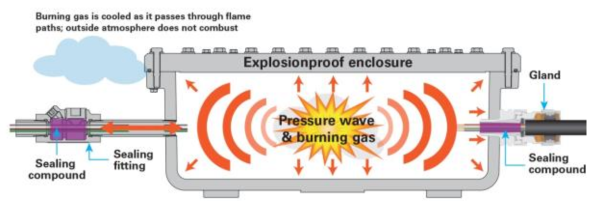

Fig. 2 Diagram showing the operation of an explosion-proof enclosure and the function of conduit cable gland seals, though a cable connector performs the same function of limiting the passage of gases and vapors and prevent the passage of flames.

II. TYPES OF SEALING COMPOUNDS

A. Cement Type Sealing Compounds

Cement types of sealing compounds are one of the oldest sealing technologies, developed and in use dating back to the early 1930's, Fig. 3. Multiple manufacturers provide a cement type of seal, though they are mostly of very similar composition. These cements are composed of mainly calcium silicates, $(CaO)_3{\cdot}SiO_2$ and $(CaO)_2{\cdot}SiO_2$. Additionally aluminum, iron, magnesium oxides and other additives are used to adjust the specific seal properties such as strength, density, and expansion. These dry powders react with clean water to harden and form a strong water-resistant seal.

The chemical reaction of hardening cement is quite complex and still not completely understood. It is believed

Fig. 3 Cement type of sealing compound in a burst pouch configuration.

that the water allows for the interlocking of layers consisting of long chains of silica and calcium oxide. These interlocking long chains give cement its robustness and the ability to resist stresses by minor tension or compression rather than fracturing [5].

Because of their long use in the industry, cement type seals are familiar to many installers and only require the addition of clean water to prepare the sealing mixture. The biggest advantage of the cement type sealing compounds, though, is cost of the raw materials, especially if purchased in bulk.

While inexpensive, cement type seals can be challenging to install which may result in a higher cost of installation. When used in conduit, the conductors are required to be completely separated so that the cement can intercalate between the wires achieving a positive seal to each wire with no leak path through the fitting. The fibrous packing materials used to separate the wires also allow for a positive dam restricting the flow of the wet cement to the seal fitting area, Fig 4. Adherence to manufactures instructions for installation and use is very important. These instructions provide the low temperature limitations of installing the sealing compound. Additionally the fitting must be maintained at or above these temperatures for at least 8 - 72 hours (depending on temperature) to achieve a sufficient cure.

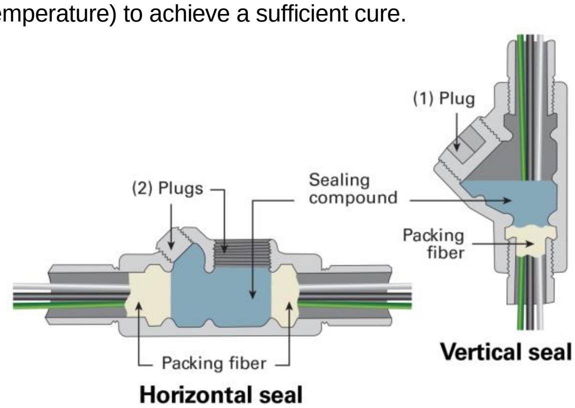

Fig. 4 Horizontal (left) and Vertical (right) seals showing the placement of the packing fiber.

Clean water and clean mixing containers can be difficult to obtain at the job site, but are critical to achieving the necessary material strength. Additionally, care must be taken to mix the cement raw material with the water in appropriate ratios as specified by the compound manufacturer. Errors in this mixing ratio can result in mixtures that are too loose or too thick and will negatively impact the material strength.

Cement sealing compounds are typically used in conduit seals, but can be used in OEM applications such as lighting fixtures and factory sealed panel boards. Bulk packaging (1–5 lbs.) of the cement type sealing compounds is the most cost effective, but pre-packaged solutions are also available. The pre-package offerings contain measured cement and clean water requiring the installer to simply burst the seal between the two compartments, knead to mix, and dispense into the fitting. Pre-packaged offerings remove any error in mixing ratios, finding clean water and clean containers that can affect the strength of the cured material.

B. Epoxies

Use of epoxy resins have grown in recent years due to their incredibly versatile properties. Epoxies are used for adhesives, coatings, and composite materials. In general, epoxies are formed from the reaction of the epoxide containing resin, e.g. bisphenol A diglycidyl ether epoxy, (Fig. 5a), with a curing resin such as an amine (Fig. 5b). This hardening reaction produces a highly cross-linked polymer (Fig. 5c). The versatility and properties of epoxy materials come from the ability to utilize different epoxy resins, hardeners, and additives. For example, to achieve a firmer epoxy, a hardener with the ability to cross-link more extensively can be utilized. Alternatively, to have a more flexible epoxy, a resin with a higher elasticity can be employed. To speed up the curing reaction a more reactive hardener can be used. Additives include catalysts which can speed up the reaction, inorganics that can alter the thermal properties, silane agents that can improve adhesion, and colorants. Tinted epoxies can help to ensure sufficient mixing and provide easy identification of the sealing compound presence.

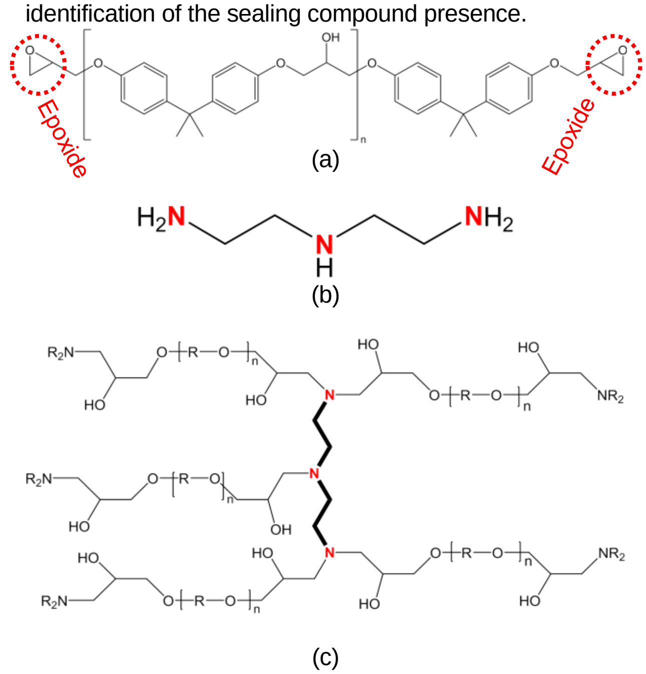

Fig. 5 Examples of reagents for an epoxy resin (a), hardener resin (b), and a cross-linked epoxy (c).

In general when adjusting the properties of the epoxy, there are always trade-offs. For example, some epoxies have been formulated to allow a quick return to service; they have a very fast cure rate. This feature is great for the installer, but is limited to small amounts of epoxy. The reaction to form the epoxy is exothermic, meaning it gives off heat as the material hardens. Larger amounts of material will generate significant amounts of heat causing the epoxy to expand during the cure and contract during the cooling process resulting in excessive shrinkage and loss of adhesion. Adhesion is critical to limiting the passage of gases, vapors, and flames.

Another example of a property compromise is the use of additives/fillers to improve the thermal properties. Additives/fillers, such as glass fibers or ceramic, can be used to lower the coefficient of thermal expansion (CTE) resulting in reduced movement of the material during thermal cycling. The trade-off here is that these additives tend to make the material more brittle and highly susceptible to cracking upon impact. Additionally, the additives make the material more prone to settling and spontaneous crystallization.

The ability to tune the epoxy formulation for a specific end use is one of the biggest advantages of using these materials as sealants. Additionally, epoxies have very good adhesion to a wide variety of substrates, including plastics (wire jacketing) and metals (aluminum, steels, brass, and copper). Most epoxies have very good chemical resistance allowing them to be used in harsh and hazardous locations, such as refineries and chemical manufacturing locations. Epoxies can operate under a wide variety of temperature ranges, e.g. -60°C to close to 150°C, while maintaining the integrity of the seal.

Due to the competing material properties previously mentioned, these sealing compounds are developed for very specific applications, e.g. a sealing compound used for a small cable gland with a quick return-to-service time. A fast curing material cannot be used in a larger sized cable gland due the excessive amount of heat that will be generated. These "designer" epoxy systems limit the economies of scale benefits and often result in high material costs. Narrow installation temperatures are another challenge to using epoxies for seals. While the operating temperature range can be quite wide, mixing and installing the two-part epoxies can only happen in a narrow temperature range. The lower the temperature, the slower the hardening or curing reaction, these types of sealants are typically restricted to installations well above freezing temperatures, similar to the cement type sealing compounds.

Shelf life of these materials can be up to two years, but many epoxies are less. Additionally, the manufactures recommended storage temperature must be observed. Many of these epoxy materials will experience settling and spontaneous crystallization, especially if they are exposed to temperatures outside the recommend limits. At its best, this settling and crystallization can cause difficulty in achieving a sufficiently mixed material. In the extreme, it can result in epoxies not mixed in the correct ratio and clogging of the dispensing system. This can result in compounds that will not cure properly resulting in an ineffective seal. If settling or difficultly in mixing is observed, installation should be stopped. These issues should be discussed with the manufacturer to ensure corrective actions for a properly installed seal are performed.

Environmental and safety considerations must be observed when using any type of sealing compound. While epoxies are relatively inert and safe to dispose of after mixing and curing, the individual components can and do have significant environmental and safety concerns. Review of the manufacturer's installation sheets and associated Safety Data Sheets (SDSs or MSDSs) will allow for the selection of proper personal protection equipment (PPE) and appropriate disposal considerations.

Epoxy sealing compounds are used in explosion proof cable glands, connectors and OEM installations (lighting products) and are available in both liquid and putty forms. The putty type epoxies come in a two-part "rope" that is kneaded to mix the two components, Fig. 6. The mixed putty can then be forced into the component and around the wires. Many of the liquid systems can be packaged to be field deployable in burst pouches or into larger dispensing systems, such as cartridges, or bulk containers for factory or OEM use, Fig. 7.

Fig. 6 Putty type epoxy sealant, the "rope" contains both parts of the epoxy. Simply cut the desired amount, knead according manufacturer's recommendations and install.

Fig. 7 Liquid epoxy offerings in burst pouch, cartridge and bulk packaging.

C. Polyurethanes

Similar to epoxies, the chemistry of polyurethanes allow for a wide variety of material properties. Polyurethanes can be rigid and flexible foams, coatings, adhesives, and sealants. Polyurethanes (Fig. 8(c)) are formed from the reaction of a diisocyanate (Fig. 8(a)) with a polyol (Fig. 8(b)). Foaming agents, catalysts, and other additives are used to tune the properties of the resultant polyurethane material [6].

One of the most recent innovations in conduit sealing uses a foaming polyurethane material [7], Fig. 9. There are numerous benefits of this sealing system due to the specific properties of the polyurethane. Polyurethanes are generally very chemically resistant. The foaming nature of the compound will separate the conductors allowing for minimal damming in vertical pour applications and no damming requirements in horizontal pour applications. The minimal damming and the 2-part mixing containers allow for rapid deployment of the seals compared to the cement type seals.

There are limits to all sealing compounds and use should be governed by the manufacturer's instructions. Installation temperatures are quite narrow and manufacturer's installation instructions should be rigorously followed. This narrow temperature range is the result of the chemistry, where low temperatures don't allow the material to foam sufficiently and at high temperatures the material will foam before application to the sealing fittings, see Installation Best Practices for Conduit Seals in section IV.B.

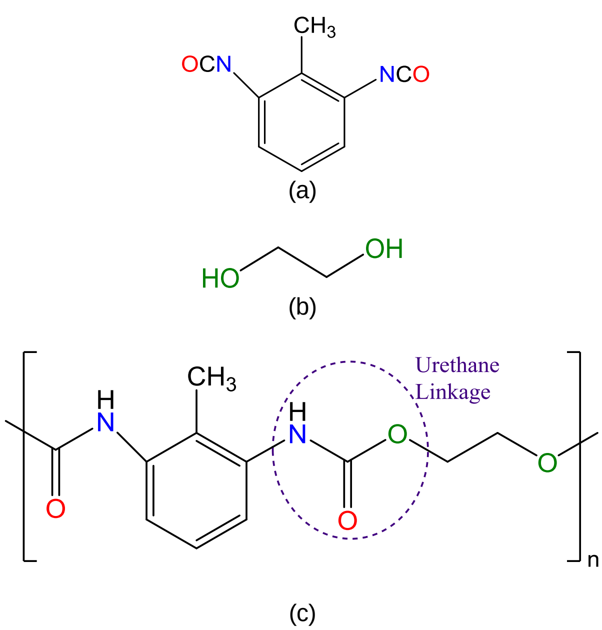

Fig. 8 Polyurethanes (c) are prepared from a diisocyanate - NCO (a) and a polyol -OH (b).

Fig. 9 Foaming polyurethane conduit sealing solution.

III. APPLICATION REQUIREMENTS FOR SEALING COMPOUNDS

Sealing compounds in electrical distribution systems for harsh and hazardous locations have many requirements that significantly limit the scope of potential materials. These demands include adhesion to different materials, wide operating temperature ranges, specific electrical requirements, chemical resistance and compatibility, field and factory usage, and stringent requirements from governing standards such as the NEC, Canadian Electrical Code (CEC), and IEC. These requirements are discussed below and demonstrate why typical off-the-shelf solutions are usually not suitable for use as sealing compounds in harsh and hazardous locations.

A. Multiple substrates

Sealing compounds are required to adhere to many different substrate materials including, metals (copper, aluminum, steel, stainless steels, and plating layers), plastics for wire jackets, and oxides from anodized coatings. Bonding of the compound to the enclosure wall, as well as the conductors passing through the enclosure is a key consideration when selecting and installing seals. The strength and adhesion properties of the compound, as well as the cleanliness, surface finish and base material all impact the finished seal. The thermal operating environment, discussed later, also plays a critical part. Ideally, the strength of the bond between the compound and the enclosure and conductors is stronger than the compound itself. Tested beyond the material limits, this type of bond will result in a cohesive failure of the material, Fig. 10. In other words, the material will remain attached to the substrate and fail within the compound. However, compounds that fail cohesively tend to have lower strength, such as the polyurethane sealants. Cement and epoxy seals generally fail in adhesion to the substrate.

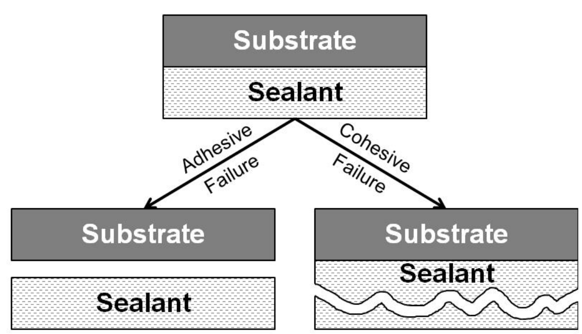

Fig. 10 Diagram showing both adhesive (left) and cohesive failures (right).

B. Operating conditions

As engineering specifications have evolved in response to the diverse environmental, hazardous area, and certification requirements of global applications, ambient temperature specifications have broadened to -50°C to +55°C ambient, with extreme temperatures down to -60°C. This can result in internal potting compound temperatures up to 125°C and higher due to the heat rise during operation. The large temperature extremes require the ability for the compound to expand and contract relative to the potting chamber. This requires a resilient compound with good toughness, a measurement of the energy a material can absorb on impact without failure. The ability for the material to flex or move during temperature cycling can be beneficial. Cements have limited ability to move and adjust to pressure over time, whereas polyurethane and epoxies have varying degrees of ability to flex. This can help the sealing materials relieve stress rather than crack or fail during thermal cycling.

C. Packaging

Some sealing compounds have been designed for a controlled manufacturing environment and thereby are not suitable for field application. Careful consideration should be given to the quality of the final product when considering selection of sealing compounds.

Sealing compounds are available in a number of different dispensing systems. The specific delivery system is dependent on where the seal is being poured, in the field or in a manufacturing environment, and on the specific type of sealant.

In controlled manufacturing installations, where a large number of seals may be made in a short period of time, bulk material or larger dispensing systems can provide cost and efficiency benefits. Field applications may have additional challenges such as fewer seals to pour where bulk material may be wasted. The seals may also be physically located further apart reducing the efficiency of pouring multiple seals.

Sealing systems are available in bulk, large cartridges (200 mL and 400 mL), small cartridges (50 mL), putty sticks that can be trimmed to a specific required amount, and burst pouches that contain the required components for a specific fitting, gland, or connector. More detail on packaging for the specific types of sealing compounds is provided in Section II.

D. Governing Standards, Codes and Directives

1) NEC: Article 500 of the NEC is the article that defines the requirements for Hazardous area equipment installation in the United States. According to the NEC the primary purpose of the seal is to <u>minimize</u> the passage of gasses and vapors as well as to <u>prevent</u> the passage of flames from one portion of an electrical installation to another. For most installations, Class I Division 1 & 2 areas are required to have a seal within 18 inches of an enclosure, and between adjacent enclosures. This method prevents pressure piling which can occur when explosions propagate along conduits or from one enclosure to another, creating pressures that exceed the designed strength of the enclosure. For the same reason, although not specifically required by the NEC, it is common practice to place seals at regular intervals between enclosures where conduit runs exceed 50 to 100 feet. Class I Division 1 & 2 areas also require a seal within 10 feet of the classified area boundary.

NEC requires that a seal not be affected by the surrounding atmosphere or liquid [1]. This is defined in UL 1203 and UL 2225 as a requirement for the compound to not soften or crack when subjected to service conditions, resist moisture and aging, and be resistant to chemical vapors as specified in UL 1203 and UL 2225 [8] [9]. The test for chemical resistance involves subjecting samples to 13 different aggressive chemicals for a period of 7 days, either as individual slugs or as part of a system. The individual slugs of material must show little to no weight or volume changes. The system samples will be subjected to explosion and hydrostatic testing and shall demonstrate no damage.

It should be noted that in addition to the effect of the environment on the sealing compound, it is sometimes necessary to consider the effects of the compound on the surrounding environment and equipment. It is well documented that outgassing of the compound can have an impact on some hazardous environment applications, sensitive to contamination, such as LED lighting and other sensitive electronics [10]. The phosphor dyes in LEDs are highly susceptible to adsorption of a number of different chemical species. The harmful chemicals will adsorb onto the LED, reducing the light output and generate additional heat. As the temperatures increase, the adsorbed materials and phosphors will start to decompose, producing irreversible damage to the LED resulting in significantly lower light output.

2) IECEx/ATEX [2]: The ATEX directive is a law of the member states of the European Union governing what equipment and work environment is allowed in an environment with an explosive atmosphere, the directive is limited to the European Union. The IECEx is an organization of industry representatives, including Manufacturers, Certification Bodies, Regulators and Users organized with the goal of developing a single certificate for hazardous area products that can be accepted worldwide. ATEX used a system of Groups and Categories, Groups 1 (mining) and II (non-mmining) and categories 1, 2, and 3 for classification of hazardous areas. These categories are identical to the one system in the IECEx. IECEx uses a classification of zones instead of the NEC defined divisions, where a IECEx Zone 0 and Zone 1 are similar to the NEC Class I Division 1 (continuous gas hazard) and Zone 20 and 21 are similar to Class II Division 1 (continuous dust hazard). IECEx Zones 2 and 22 are equivalent to Division 2 areas. In an attempt at harmonization, the NEC has also adopted Zone classification as an alternative to division classification. This topic has been discussed in previous PCIC papers [11] [12].

Following the IECEx/ATEX harmonization, potting compounds are treated a little differently as compared to the NEC standards. For instance, the IECEx/ATEX do not require chemical compatibility testing [13] [14]. They do however require a more stringent test of the compounds sealing capabilities. This test method consists of establishing the reference pressure, which is the maximum expected pressure for a sealing compound in its intended application. Once the reference pressure is established, potted samples are subjected to a sequence of tests to simulate extreme operating conditions, including a hydrostatic pressure blotting test at 4 times the reference pressure, followed by 4 weeks of accelerated aging to simulate sustained use in the anticipated environmental conditions. After, conditioned samples are again subjected to a hydrostatic pressure blotting test. The IECEx/ATEX hydrostatic pressure blotting test differs from the NEC pressure test in that the samples are not allowed to leak before or after environmental conditioning. However a recent change to the standard has permitted minimal leaking after conditioning but requires additional erosion and explosion testing for flame propagation. If the samples pass the flame propagation test then they are accepted as flame tight.

IV. INSTALLATION BEST PRACTICES

A. General Considerations

Almost all sealing compounds found in conduit seals, cable glands, and connectors have installation challenges, but they are a critical component to a safe electrical distribution system in harsh and hazardous locations. This section is intended to assist in the installation of various sealing systems by providing best practices to installing a seal that will function as designed. When installing sealing compounds, attention to detail is imperative. **Always follow the manufacturer's instructions and recommendations.** Taking the two to three minutes to read and review the instructions may save the time, effort, and cost of tearing out an improperly installed sealing compound or, at the extreme, a catastrophic incident.

Table I illustrates a few general factors that should be taken into account when any sealing compound is specified or installed. The implications of each general consideration are described with recommended best practices provided at the end of the section.

1) Temperatures: Sealing compound storage temperatures can have a significant impact on product quality and performance. Some sealing compounds have very narrow storage temperature recommendations. Low temperatures can contribute to compound crystallization and/or settling. Evidence of crystallization/settling is seen in clumpy and hardened burst pouches and clogging and bursting of dispensing equipment. This crystallization/settling will have a significant impact on the mixing, curing, and can lead to sealing compound failure. Once crystallization/settling has occurred it can be difficult to recover the mixture in bulk form, or impossible to reconstitute in burst pouches or cartridges.

High storage temperatures have a number of negative implications as well. Components can decompose, lowering shelf life. High temperatures can also increase the diffusion of the components through the packaging, potentially causing some hardening effects and altering the mix ratio when finally mixed.

Best Practice: Sealing compounds that show any hardening or crystallization should not be used before contacting the manufacturer to determine whether the material is usable or if there are any remediation actions possible.

Table I.
A brief comparison of the three different types of sealing compounds used in harsh and hazardous electrical distribution systems.

Sealing Compound	**Cement-Type**	**Polyurethane**	**Epoxies***
Humidity	sensitive	sensitive	insensitive
Storage Temperatures	No limits	10°C to 30°C	-40°C to 35°C
Install Temperatures	>10°C	10°C to 30°C	> 0°C
Operating Temperatures	-40°C to 74°C	-50°C to 60°C	-60°C to 150°C
Shelf Life	12 mo.	18 mo.	12-24 mo.
Cure Time	8 - 72 hrs.	20 min.	2-24 hours
Sealant Form	Powder/ liquid	2-part liquid	2-part liquid or putty
Products used in	Conduit, OEM	Conduit, OEM	Connectors, Cable Glands, OEM

*There are a number of different epoxies used in harsh and hazardous electrical distribution systems with a wide range of properties. Ranges expressed in the table are for various epoxies used in harsh and hazardous equipment, specific epoxies will have explicit values.

Installation temperatures are also important, as previously discussed in Section II. All seals are chemical reactions which are very sensitive to temperatures, the colder the temperature the slower the reaction, conversely the warmer the temperature the faster the reaction. Colder temperatures and slow reactions can lengthen the return to service time or even halt the cure all together. Cement-type sealants can freeze, damaging the seal and fitting. At low temperatures expanding foam seals will not expand to the specified volume rendering the seal ineffective, Fig. 11. High temperature installations can cause very fast reaction rates, which may result in very high sealant temperatures due to the exothermic nature of these reactions. Too high a compound temperature will result in excessive compound shrinking as it cools resulting in loss of adhesion and seal protection failures.

Fig. 11 Foaming polyurethane seal poured below the recommended temperature. The low temperatures limited the foaming reaction resulting in an insufficient seal near the top of the fitting.

Best Practice: For colder temperatures, tenting and heat tracing the fitting, gland, or connector can be a suitable strategy to achieving the specified installation temperature. The specified temperature should be maintained not only during the seal pouring, but throughout entire seal curing reaction as well. Additionally, the sealing compound should be at the specified temperature. This can be accomplished by keeping the material in a warm vehicle or in a jacket interior pocket using body heat to warm the material.

2) Shelf life: Shelf life should be clearly indicated on sealing compound packaging; the manufacturer should be consulted if shelf life is not provided. Many sealing compounds have a shelf life of 1 to 2 years. After this time, the potential for components to degrade significantly increases, negatively impacting the material properties and increasing the risk of achieving an improper seal.

Cement-type sealants will react to moisture when the storage temperature drops below the dew point. This will cause clumping and hardening of the cement, changing the strength and flow properties. Unmixed epoxies and foaming sealants will also react to humidity resulting in a change to the material properties. Burst pouches and cartridges have varying degrees of permeability and do not always provide impervious moisture protection to the compounds.

Best Practice: Expired material should never be used and should be disposed of properly. Smaller quantities can help control inventory and reduce potential waste and reduce the possibility of using outdated material that will produce a seal out of specification.

3) Cleanliness: Sealing compounds are designed to adhere to multiple substrates, or surfaces, such as metals, plastics, and oxides (anodized surfaces). The adhesive bond to the substrate is key to providing a seal that limits the passage of a flame and/or flammable gases and vapors.

Best Practice: Prior to installing a sealing compound, the conductors and the fitting, gland, or connector should be inspected for cleanliness. All dirt, debris, oils and fluids should be removed. Particular attention should be paid to any thread lubricants that may have migrated to the sealing area. Pulling lubricants should never be used in an area to be sealed and wire impregnated with lubricants should be avoided whenever possible.

The use of an alcohol wipe or citrus wipe can help to remove any oil or grease residue. After cleaning, allow for the sealing components and conductors to completely dry prior to installing the seal.

4) Equipment and sealing compound: Sealing fitting, cable glands, and cable connectors have been designed, tested and certified as a specific system. Rarely will one equipment manufacturer certify their equipment with another manufacturer's sealing compound. Modifications to the substrate (such as coatings) that have not been certified as part of the system should be avoided.

Best Practice: Ensure the sealing compound and the equipment is rated to be used together. Avoid mixing of different manufacturers' equipment and sealing compound unless specified by the equipment manufacturer.

B. Conduit Seals

Conduit sealing is limited using either a cement or expanding foam sealing compound. Epoxies sealants have not been certified for use in conduits seals, most likely due to their high costs and installation complexity. The choice of sealing material will depend on gas group classification, fitting size, and, of course, material and installation costs, Table II. In addition to the general considerations discussed above, there are a few installation best practices specific to conduit seals.

Table II.
Selected Conduit Sealant Properties*

Sealant	**Cement-Type**	**Foam Polyurethane**
Cost	$	$ $ $
Install Time	More Time	Less Time
Fitting Size	½" – 4"	½" – 2"
Group Rating	B, C & D	C & D
Horizontal Orientation Damming	Required	Not Required
Vertical Orientation	Wire separation and damming	Damming only

*Epoxy sealing compounds are currently not certified for use in conduit seals.

1) Moisture: The potential for moisture is always present in electrical distribution systems through normal "breathing" of the systems due to environmental fluctuations [15]. This moisture can negatively impact the integrity of the seal and can damage the conduit from oxidation. Conduit seals are available with drains that allow condensation and standing water to be removed from the fitting. These fittings either have a tube (for the foaming polyurethane sealant) or a removable plug that produces a drain path (for the cement-type of sealant). When pouring conduit seals with drains, care must be taken to ensure that the plug or drain tube is not covered with sealant as this will eliminate the drain path, Fig. 12.

Fig. 12 Drain seal fitting showing the lack of any draining capability when the drain tube is covered with sealing compound.

Best Practice: Moisture will normally be present in an electrical distribution system and must be addressed to maintain the integrity of the system. The use of sealing fittings with drains and a robust seal inspection program including drain maintenance, see below, can go a long way in reducing the negative impact of moisture on the system.

2) Damming Requirements: In a vertical orientation both cement-type and foaming polyurethane sealants require damming to restrict the sealant to the fitting. Manufacturer's recommend packing material should be used for damming the fittings. The material should be packed tightly and any loose packing material in the fitting and around the conductor should be removed to eliminate any potential leak paths. For horizontal orientations a seal utilizing the cement-type of seal is required to be dammed, whereas the polyurethane seal requires no damming. Cement type fittings also require the separation of the conductors to ensure no leaks between wires can occur, Fig 13. In one study it was shown that improper installation resulted in the lack of conductor separation for 50% of the conduit seals [16]. The foaming action of the polyurethane sealants will separate the conductors, providing a sufficient seal around each conductor as well as reducing installation error and time.

Best Practice: All vertical orientation seals require damming. Only cement-type seals need damming in the horizontal orientation. All cement-type seals require conductor separation.

Fig. 13 Figure showing the damming and conductor separation required for cement type of sealing compounds.

3) Seal Maintenance: In most mechanical and electrical systems, maintenance is critical to ensure a safe and reliable system; sealing systems are no different. Depending on the installation quality and environment, the presence of water and thermal fluctuations, seals may deteriorate over time. An inspection program can help maintain the integrity of the entire electrical system by ensuring the seals are performing as expected and any that have started to deteriorate are replaced.

Seals should be inspected by removing the plug and performing a visual inspection by looking for any cracking, flaking or general deterioration. Gently poke the seal to evaluate the overall hardness and integrity of the material. Cement seals should maintain their hardness and show no signs of degradation; foam polyurethane seals may have a range of hardness, but should be at least as hard as a rubber tire. Any suspect seals should be replaced as soon as possible.

The inspection program should include a seal numbering system, inspection logs and an identification tagging system to allow for easy identification of a seal and inspection history. Each seal should be inspected after curing (before energizing) and on a yearly basis. The yearly inspection can be accomplished by checking a few seals each month during normal plant maintenance.

Seal retrofit fittings are available that allow for replacement of a seal fitting without the disassembly of the conduit system, Fig 14. The existing seal, sealing compound, and damming fiber should be carefully removed as to not damage the conduit or the conductor insulation. The retrofit seal can then be installed according to the manufacturer's instructions and a new seal poured.

Best Practice: A conduit seal inspection program will help to ensure the integrity of the seals and that this critical piece of the electrical distribution operates as intended.

Fig. 14 Retrofit sealing fitting allow for easy replacement of conduit seals.

4) Pouring Multiple Conduit Seals: Typically more than one conduit seal will be present in an electrical distribution installation. Multiple seals can be poured at one time with one batch of the cement-type or with one cartridge of the foaming polyurethane sealant. This strategy can save time and money.

Some consideration must be given to the logistics of the multiple conduit seal pour. For the cement-type of sealants, material should only be mixed in amounts that can be poured in 15 minutes. Any longer and the material will begin to thicken. The thickened material will be more difficult to dispense into the fitting and, more importantly, will not flow sufficiently around the conductor to achieve a proper seal. For the foaming polyurethane seals the multiple seals should be quite close together to ensure the material continues to have foaming action when being poured. Each fitting type has a required volume of sealant, too much and excess sealant will expand in the conduit system, too little and an ineffective seal will be formed.

Best Practice: Multiple conduit seals can be poured at one time for both cement-type and foaming polyurethane sealants. Care must be taken to ensure the proper amount of sealant is installed and that the time between mixing and pouring the last seal is not so long that the sealant has begun to harden.

C. *Cable Glands and Connectors*

Cable glands and connectors use very similar or even the same sealing compounds. Typically epoxies are used and can either be in a liquid or a putty form. Both putty and liquid forms have advantages and disadvantages, Table III. Cement and foaming polyurethane sealants are not certified, most likely due to the wide temperature ranges required for the cable glands and connectors. Two-part liquid epoxies are quite easy to install as long as the gland or connector can be placed in the correct vertical orientation. Fig. 15 shows exemplary liquid seals used in a cable gland and a cable connector. Epoxies are very good adhesives and care should be taken to only apply the epoxies to the desired areas. An untidy installation can result in maintenance difficulties in the future from unintended gluing of components.

Table III.
Epoxy Sealant Properties*

Epoxy Sealant	**Putty**	**Liquid**
Cost	$	$ $ $
Ease of install	😐	☺ ☺ ☺
Orientation	Any	Vertical Only
Return to service/ Re-energize Time	> 24 hrs.	0.25 - 24 hrs.

*Cement and polyurethane sealing compounds are not currently certified for use in cable glades or connectors.

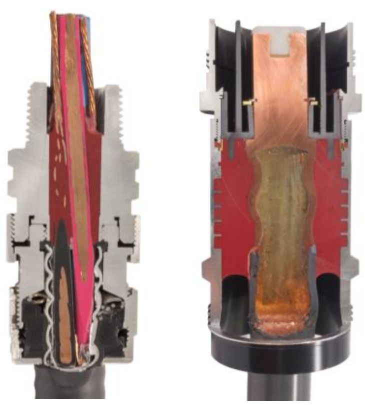

Fig. 15 Liquid seals for a cable gland and a cable connector showing good fill and robust seal.

For installations where it is difficult or impossible to get the correct vertical orientation, the putty form is a good alternative to liquid epoxy. The putty is a two part “rope” that is kneaded by hand and pressed into the gland or connector.

Best Practice: The selection of a liquid or putty epoxy seal for cable glands or cable connectors will depend on:

- Whether the gland or connector can be placed in a vertical orientation. If not, the putty form must be used.
- Return to service time. Typically liquid epoxies are formulated to have relatively quick return to service/re-energize times compared to the putty form.

Two part epoxies need to be mixed prior to installation. It is important to ensure the two parts, whether as putty or a liquid, are completely mixed. Some materials have two distinct colors which allow for a visual indication of complete mixing. Complete mixing will produce a consistent color with no striations and properly mixed putties will feel like warm play dough. Failure to mix completely and insufficient packing of the putty will result in gaps (Fig. 16) or potential leak paths allowing the flow of explosive gases, vapors and flames.

Best Practice: Ensure the two part epoxies are mixed sufficiently, packed tightly, and evenly distributed around the conductors.

Fig. 16 An example of a poorly installed putty seal. Notice the mottled appearance from incomplete mixing of the putty and the gaps in the seal where flames, gases and vapors can potentially pass.

V. CONCLUSIONS

Seals, whether a conduit seal, cable gland seal, or seal connector, are integral parts of a safe electrical distribution system in harsh and hazardous environments. These sealing systems are required by various standards bodies such as NEC and IEC for Class I Division I and II and Zone I environments [1][2]. Due to the complexity and cost of installation, proper re-classification of an area to one which reduces required seals can be an economic benefit. But there will always be areas that are required to have seals in one form or another, whether in conduit, cable glands or cable connectors.

General considerations that will allow for a proper and safe installation of sealing systems include:

- Follow ALL manufacturers’ installation instructions and pay attention to the details of the installation.
- Pay close attention to both the installation temperature and the temperature during the entire curing process. Seals are formed through chemical reactions and are highly dependent on temperature.
- Select sealing compounds that reduce user error and time required to provide a safe installation.
- Institute a seal inspection program. Seals should be inspected after curing (before system is energized)

and on a yearly basis. Suspicious seals should be replaced as soon as possible.
- Condensation, particularly in conduit systems is a major factor in the maintenance frequency of seals. A well designed and properly draining conduit system will minimize the frequency of seal replacement.

There are many sealing options available for harsh and hazardous area environments. Having a working understanding of the benefits and installation & maintenance requirements of the various options will help in selecting the proper method for your application. Proper maintenance of previously installed sealing systems will avoid costly new installations that result from corrosion, freeze/thaw cracking, electrical performance and other safety issues. Often, an understanding of the root cause of maintenance problems can drive smaller retrofits that target problem areas and avoid major system redesigns.

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VIII. VITAE

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