Flexible electric heating

for potentially explosive atmospheres

by Frank Merkel

Figure 1: Chemical industrial complex at night-time

Everyone knows about the importance of heat or to be more precise: The right temperature. What is true for us humans also similarly applies to technology. The benefits of using electricity as a heat source are obvious: electricity is financially attractive. Electricity is environmentally friendly. Electricity is safe. Therefore more and more manufacturers rely on flexible electric heating in explosive atmospheres.

Electric heating is not restricted to certain industrial areas or specific applications. It can be utilized universally. Its physical principle of resistance heating allows electric heating to be applied deliberately in required areas and only in times when heating is required. Such flexible handling allows economic heating of large and small systems alike. The main benefit of electric heating solutions, however, is the custom benefit, whether for retrofitting of existing systems or planning of new projects.

Aside from classic application types such as frost-protection, temperature conservation and temperature increase, various further application types are possible and have recently started being utilised by the industry. Prevention of temperature fall below dew point, for example, is a major issue in many analytic applications to avoid wrong measuring results.

The most popular and probably most conventional type of electric heating is resistance heating by means of heating conductors on pipes or hoses with a thermal insulation made of materials appropriate for a certain type of application.

Sensors integrated into the heated object measure the temperature which is analysed in a temperature control unit. The heating conductor is supplied with voltage according to the control unit's configuration and the required process temperatures. The heat energy generated in the conductor due to the voltage drop is directly transferred to the object to be heated, until the desired process temperature is achieved.

Such resistance heating is also applied in areas with flammable gases, vapours, fluids or dusts. This however requires special attention as potential explosions pose a permanent and considerable risk. Under certain conditions an explosive mixture might be created with the existing oxygen in the ambient air. A spark therefore might lead to an explosion. These so called ex-areas can be found in various industries such as the chemical or pharmaceutical industry, refineries, fuel depots or varnish factories, as well as in wood or food processing applications such as mills and grain silos with degassing or dust forming substances.

Special provisions during planning, design and construction of electric trace heating systems for these explosive atmospheres as well as specific mounting and operating conditions are prerequisites for a safe and intended operation according to the European Directive 94/9/EC [1].

The Winkler GmbH in Heidelberg, Germany, has been developing flexible electrical heating systems for explosive atmospheres for more than 33 years. The respective Winkler departments particularly pay attention to custom solutions for specific heating applications in close cooperation with the client. Every single heating solution is unique and specifically tailored to the client's requirements and processes.

In the last years clients began requesting more specific and demanding applications. Flexible and broad applications especially for explosive atmospheres are required without compromising on safety. Predictable fault sources during operation or due to the incorrect handling of electric heating must be excluded as far as technically feasible, and be properly documented.

Safety was and still is a major challenge which Winkler was able to master in the last years. This success is reflected in a wide range of type WEX systems-certified electric heatings for explosive atmospheres (heated hoses, heated lines, heating jackets and temperature controllers). The major benefit of Winkler WEX products: they do not comprise multiple individually certified components (such as heat conductor, bushes, temperature sensors, etc.) that require acceptance inspections on site by independent experts. ›Systems-certified‹ by Winkler means that only one EC-type examination certificate and one detailed documentation for the intended operation in ex-areas is required. This is a considerable simplification for the system's operator who is obliged to create and provide the required documentation after completed risk assessment compliant to §3 of the German Ordinance on Industrial Safety [2] (Betriebssicherheitsverordnung – BetrSichV). An additional acceptance test of the ex-product on site is no longer required.

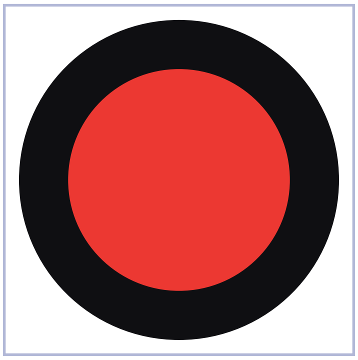

Figure 2: Winkler: Heating to the point

Legal basis for systems-certified electric ex-heatings

The introduction of the EU Directive 94/9/EC [1] in 1996, specifically targeted at manufacturers, made it increasingly difficult to find suitable products and components for electric ex-area heatings on the market.

Excerpt from the Directive 94/9/EC Article 2 paragraph 1 [1]: ›Member States shall take all appropriate measures to ensure that the equipment, protective systems and devices referred to in Article 1 (2) to which this Directive applies may be placed on the market and put into service only if, when properly installed and maintained and used for their intended purpose, they do not endanger the health and safety of persons and, where appropriate, domestic animals or property.‹

This statement summarises all requirements, directives and standards: ›Safety comes first‹. ➔

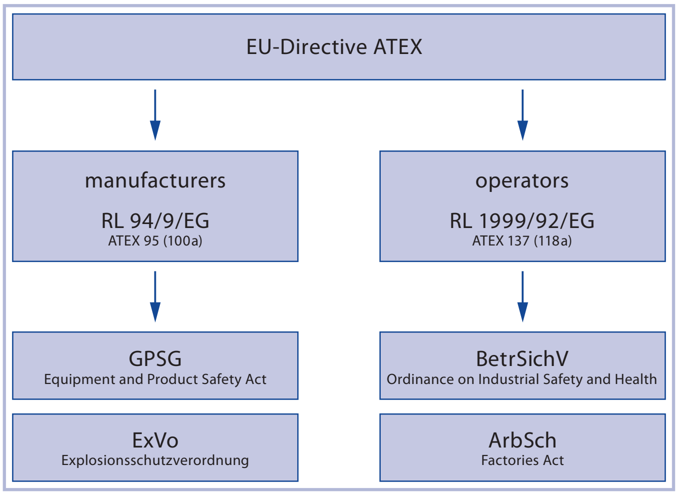

Figure 3: EU Directive ATEX for manufacturers and operators

Furthermore, additional national regulations, directives and laws apply and need to be complied with by manufacturers of ex-area electric heating and operators of systems in explosive atmospheres (Figure 3).

94/9/EC [1] was the first directive to contain concise and harmonised statements on requirements for non-electric components and products. Products intended for use in explosive atmospheres due to dust formation, or safety systems and security devices for use outside of explosive atmospheres which contribute to a safe operation of products inside explosive atmospheres.

Compared to earlier national regulations for intended operation in explosive atmospheres this means an extended responsibility for manufacturers and operators.

The manufacturer now has to carry out an ignition risk assessment according to EN 13463 [3] upon selection and use of components not directly related to electrical components. Such an assessment shall ensure that the manufacturer's product does not pose any danger. The safety shall also be guaranteed in the case of a predictable fault, and appropriate provisions – mainly affecting technical equipment – for these cases must be provided.

With the introduction of the 94/9/EC [1] Directive, not only electric heating components but also non-electric components – and especially plastics – shall now be considered carefully. Plastics are known for their property to store electrostatic charge and release this charge instantaneously in the form of an arc and ignition spark towards an object with reversed potential (explosion risk ›electrostatic charge‹). This danger shall be prevented by proper design measures.

Approval of release and marketing of electrical heatings for explosive atmospheres is subject to a fixed certification process. This certification is performed by so called notified bodies which evaluate a sample of the Ex-area product according to directive 94/9/EC [1]. Upon passing the certification the product receives the relevant EC-type examination certificate for those standards that apply to the product (DIN EN 60079-ff [8]).

Besides the extensive testing and certification process the manufacturer also needs to operate a quality management system which must be certified and regularly inspected by the notified body. A yearly inspection of Ex-area product manufacturing according to DIN EN 13980 [5] criteria is also mandatory.

Systems-certified explosion protected products

Until recently, just like any other manufacturer Winkler GmbH manufactured individual components for their Ex-area heating solutions. The Heidelberg-based company has, however, adapted to higher market demands. In 2006 Winkler developed the first completely systems-certified Ex-area heated hose and the first Ex-area type WEX 8000 heated line. These products made Winkler the first manufacturer in the industry to integrate customer-specific requirements into ex-area products with this kind of certification.

The modular approach of the Winkler Ex-heated hose enables the customer to order exactly the required line for each individual type of application. Lengths of up to 50 m and differing base hoses with varying inner diameters are possible depending on the application. A wide range of controllers offers various connection types. Interchangeable inner lines made of different materials are suitable for a variety of industrial applications. Optional sensor positions exactly determine the temperature and control it according to process requirements (Figure 4).

Another special feature of the explosive atmosphere heating is its completely anti-electrostatic design, enabling operation in Ex-areas without restrictions and without an additional earth conductor. As these heatings are often used in mobile operation, and therefore subject to high mechanical stress, all materials need to be rugged, simple and highly efficient.

The type WEX 8000 heated line was followed by further models. Today more than a thousand applications – and customer-specific models can be manufactured. In 2011 all Ex-area heating jackets and drum heaters – designed on the same basic principle as Ex-area heated hoses and heated lines – were systems-certified.

All Ex-area type WEX... electrical heating systems are suitable for operation in explosive atmospheres in Zones 1 and 2 as well as explosive dust atmospheres in Zones 21 and 22. Therefore they can be universally operated in various industries and industrial applications with explosion groups IIC (such as hydrogen) and IIIC conductive dusts (such as carbon dust) for process related heating.

WEX heated hoses and WEX heated jackets feature an enhanced temperature range compared to EN 60079-0:2006 chapter 5.1.1 [9] with -40°C to +85°C and -40°C to +60°C respectively, extending their operational range even under extreme ambient conditions.

Design fundamentals for electrical heating systems in explosive atmospheres

Heating plays a vital role in the transport of gaseous, fluid and solid material from A to B. Electrically heated hoses for example serve the purpose to preserve the properties of the medium up to the point of delivery. Many different application types for frost protection, temperature conservation and temperature increase can therefore be achieved.

An example of this would be the prevention of temperature shortfall below dew point. The medium temperature is being kept stable at its ideal material-specific temperature during transport in order to avoid separation (such as water) due to chemical composition. Such separation would undoubtedly lead to wrong measurements in subsequent analysis. Transport or filling of fluid or solid materials often requires trace heating as well to guarantee proper flowability. During non-heated transport the medium might stick to the inner hose wall and subsequently block it. This may be prevented by heating the medium. Another large application range for electric heating includes enhancement of production processes or filling of heated media for subsequent processing. Examples for such applications are drum and container heaters, mainly used in mobile operation. For a secure electrical connection, pre-mounted Ex-area terminal boxes from R. STAHL are in use (Figure 5).

As such applications often include explosive atmospheres, special consideration must be placed on design and production of these boxes. →

Figure 5: WEXH… heating jackets (IBC container heater / 200 L drum heater) with Stahl terminal boxes for lead connection (power / sensors)

Figure 4: WEX8000 ATEX heated hose / ATEX heated line

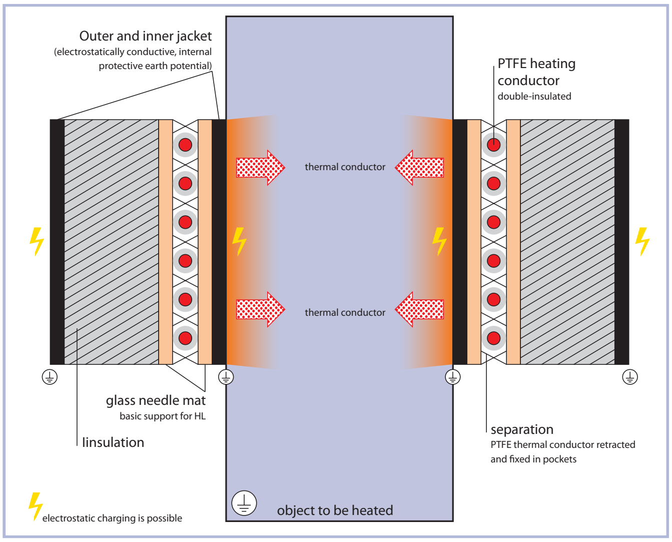

Figure 6: Functional cross-section of a WEX heating jacket

The material to be heated is the main reason for the formation of explosive atmospheres. It might be classified as a hazardous substance due to its chemical properties and can only be stored, transported and processed under strict safety precautions.

A risk assessment needs to include the prevailing operating and ambient conditions as well as, probable operating errors due to negligence or missing information on installation and operation.
While ›normal‹ electrical heating systems (outside ex-areas) can be offered and used in various designs, the options for specific explosive atmosphere heating are limited. Fundamental safety aspects need to be considered to prevent damage – explosion at worst – during operation.

It is the manufacturer's responsibility to guarantee product safety by implementing appropriate technology and design solutions. Restrictions to operation in the installation and operating manuals should be avoided if possible.
All electric heatings comprise two components essential for explosion atmosphere safety: the electrical components and the non-electrical components.

Electrical components

The electrical components include the heating conductor, the connection bushing and the temperature sensors.
Due to their physical properties these components can – even under normal operational environments – be considered as primary ignition sources. They must not act as an ignition source or generate sparks during switching operations (Figure 7).

The heating conductor (1) comprises a base insulation (2) that needs to withstand the temperatures at the conductor, and an additional insulation (4) that protects against external mechanical stress. This ensures a combination of electrical safety (primary insulation) and mechanical protection (additional insulation) which is fundamental for operation in explosive atmospheres. The protective braiding (3) located between both insulating layers is an additional safety measure that comes into effect when the outer insulation is damaged. It trips upstream protective devices (fuses, FI circuit breakers). The PTFE connection bushing is yet another electrical component, connecting the heating conductor with the so called thermistor. The connection of both conductors is located within the silicone-encased connection bushing. The transition point is therefore air- and gastight.

Further important electrical components include two temperature sensors for measurement of control temperature (control sensor) and maximum permitted temperature (limiter sensor).

For the external connection of heating conductors and temperature sensors the R. STAHL Ex e (grid) and Ex i (sensors) terminal boxes are in use (Figure 8, 9, 10; see on the right side).

Non-electrical components

Non-electrical components include any further materials such as the outer jacket, insulation, mounting straps, protective hoses and many more. These components combine to provide maximum mechanical protection for the electrical components.
With the introduction of the 94/9/EC Directive the non-electrical components are subject to a separate risk assessment. Possible dangers during intended use shall be analysed beforehand. The ignition risk assessment according to EN 13463 [3] must include all relevant components. It shall pay particular attention to an ignition risk due to electrostatic charging of the heating jacket's outer sheathings or the heated hose's corrugated hose during operation.

Prevention of outer jacket electrostatic charging

The EN 13463 [2] ignition risk assessment particularly focuses on the electrostatic dissipation capability of heating systems for explosive atmospheres. In mobile operation the risk of ignition is higher due to various materials touching.

The TRBS 2153 [6] and BGR 132 [7] address prevention of ignition risks due to electrostatic charge. They include fundamental measures to support the operator with risk assessment in compli-

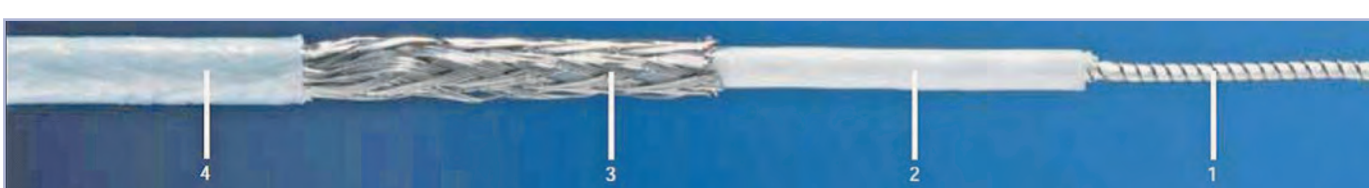

Figure 7: Ex heating conductor with twin PTFE insulation and protective braiding

Figure 8: Fibre glass tissue with PTFE heating conductor

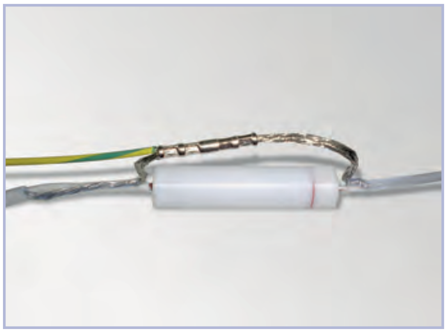

Figure 9: PTFE connection bushing

Figure 10: R. STAHL terminal boxes Ex e / Ex i for connection of heating and temperature sensors

ance with the industrial safety regulations.

These TRBS 2153 [6] or BG 132 [7] regulations are applied for assessment and prevention of ignition risks and provide a basis for design and construction of components.

The following issues are to be considered:

- Equipment and devices in potentially explosive atmospheres must not become dangerously electrostatically charged.
- The use of equipment or systems made of insulating materials in explosive atmospheres should be avoided or appropriate countermeasures against dangerous electrostatic charge should be taken.
- Generally only conductive or dissipative devices or systems shall be used in explosive atmospheres. Integration into the system's equipotential bonding is mandatory.

Materials are divided into three types depending on electrical conductivity:

conductive			static dissipative					insulating			
10^1	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9	10^{10}	10^{11}	10^{12}
Surface resistance Ro in Ω/m											

Figure 11: conductive materials, insulating materials, surface resistance: material properties concerning electrostatic charging

A Material with a resistance of more than 10^4 Ω/m and less than 10^9 Ω/m is considered dissipative. Ambient temperature and relative humidity are important factors for this value (e.g. a higher humidity increases the dissipative properties of a material).

Quotation from BGR 132 Section 3.1.1: ›Depending on the likelihood of ignition, all objects and equipment made of conductive materials must be earthed and those made of materials capable of dissipating static charge must be provided with earth contact. Earthed conductive objects cannot become statically charged to a dangerous level. However, if they are insulated from earth, spark discharges can occur.‹ The technical regulations on industrial safety TRBS 2153 ›Prevention of ignition risks due to electrostatic charge‹ contains specific requirements for the use of conductive and dissipative materials.

According to DIN EN 60079-14 (VDE 0165-1) [8] Chapter 6.4 non-metallic materials require specific measures to reduce the effects of electrostatic electricity to a non-hazardous level, i.e. the insulation resistance or surface resistance must not be greater than 1 GΩ/m (10^9Ω/m).

Bringing two different materials into close contact, charge carriers move from the material with lower electronic discharge energy to the material with higher discharge energy. In case one →

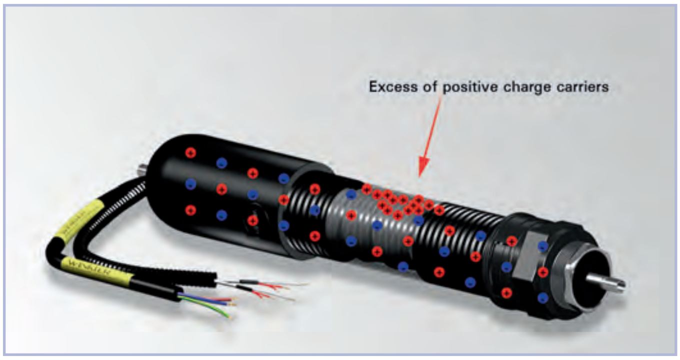

Figure 12: Electrostatic charging of a heated hose

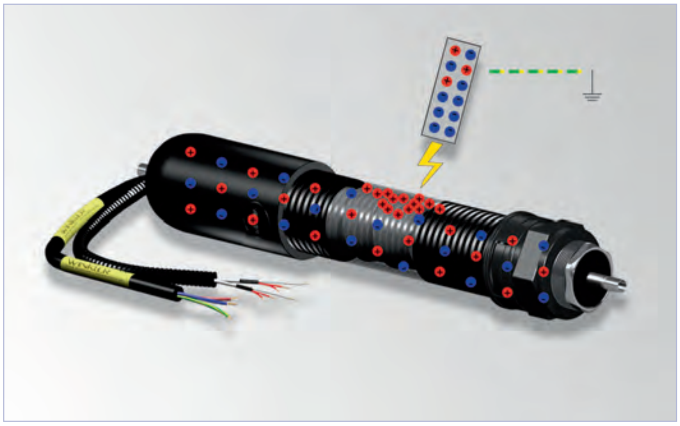

Figure 13: Electrostatic discharging of a a heated hose

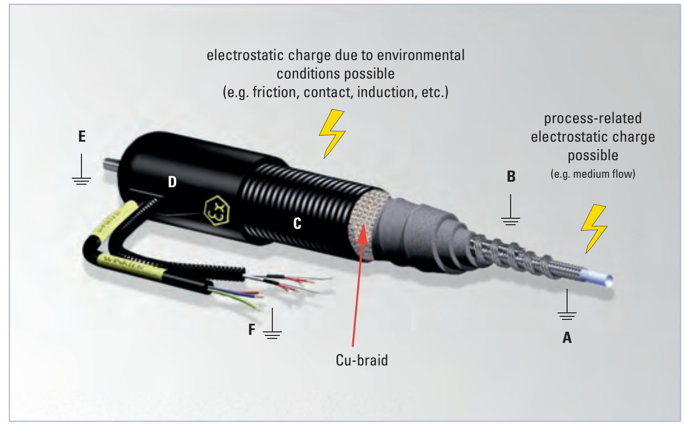

Figure 14: Electrostatic charging due to environmental conditions is possible (i.e. friction, contact through persons, induction, etc.)

of the materials has insulating properties, a fast separation of these materials might lead to excess electrons remaining in the other material. This results in potential differences. Induction also leads to dangerous charge separation since it might not be recognized at first and accumulates high ignition energy over time (Figure 12).

This accumulated static energy is especially dangerous in potentially explosive atmospheres. It is thermodynamically instable and tries to compensate this state by electrostatic discharge. The type of discharge (such as spark discharge) is an important factor.

When humans are involved in these discharge processes, the fingers might act as ignition electrodes discharging to earth potential. Reversely, the person might be charged with thousands of volts. Such discharge energies are sufficient to ignite flammable fluids, gases, vapours and dust.

Electrostatic charges might not be detected at first and their place of formation is complicated to assess. Therefore the relevant regulations and directives demand the use of conductive or dissipative materials.

The safe operation of electrically heated lines and hoses in explosive atmospheres requires all possible risks during intended and predictable faulty operation to be detected by the risk assessment and appropriate countermeasures to be taken.

Heated lines and heated hoses comprising several components certified for Ex-areas but without systems-certification of the manufacturer must be inspected on site and a risk assessment must be undertaken. Such an assessment can only be carried out when the manufacturer provides all relevant material data sheets and the operator of the system is capable of proper evaluation. This requires extensive knowledge and a specific education. Therefore notified bodies gain more importance when it comes to complete system assessments.

The inspections specifically evaluate the exterior design, the corrugated tube and the connectors. The design should not only contribute to mechanical protection. It must be considered in the risk assessment of the complete system. Tests on typical environmental effects, material aging, hydrolysis and impact resistance are mandatory for a successful certification and safe operation in explosive atmospheres.

Discharge processes with people involved are difficult to evaluate beforehand. Therefore, concise and unmistakable operating instructions with rules for handling and operation of heated lines and heated hoses in explosive atmospheres are essential.

The danger of electrostatic discharge can be demonstrated using a simple example:

When a person is being charged to a voltage of 2kV (perceivable upon discharge by the person), the spark discharge contains all energy accumulated in the person (similar to a capacitor). Since the person can be considered a conductor, it has a measurable capacity against earth of about 100 to 200 pF – an energy level sufficient for almost all flammable fluids, gases, fumes and dusts to ignite.

Explosion-protected heated lines and heated hoses from Winkler are made of electrically discharging materials (outer jacket and connectors) that prevent electrostatic charge build-up.

Figure 14 shows the main areas of heated lines and heated hoses subject to electrostatic charge and possible discharge types:

A The PTFE hose is earthed via its steel braid,
B The insulated PTFE heating conductor is earthed via its metal protective braiding,
C The outer jacket (corrugated pipe) is electrostatically dissipative and connected to the silicone caps or threaded connectors, a Cu-braid with large contact area serves the purpose of connection to the conductor system,
D The silicone caps or threaded connectors are electrostatically dissipative and connected to the corrugated pipe,
E The controllers are connected to the braided PTFE hose and are integrated into the safety measures of the complete system,
F Protective conductor connection (PE / 2.5 mm²) in mains cable.

The electrical connection (protective earth in mains cable) and the controllers enable a connection of the ATEX heated hose to the on-site equipotential bonding system.

The following process permanently takes place in Winkler AT-

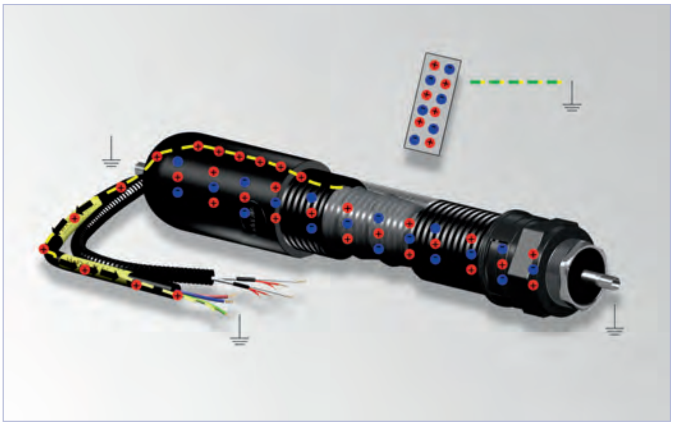

Figure 15: Prevention of electrostatic charging

EX heated lines and heated hoses with electrostatically dissipating properties of components (corrugated pipe, silicone caps):

Charge separation by friction or induction, causing an energetic thermodynamic state, is being neutralised by continuous electron flow over the protective earth conductor system, thus preventing build-up of dangerous charge accumulation. Closing-in objects won't cause charge separation, effectively preventing sparks due to charge compensation.

During risk assessment all materials and components need to be inspected and tested on their interaction with other components. The following factors play a vital role in this process:
Not only the electric heating inside the tube, but also the adjacent components, need to provide appropriate protection against damaging environmental effects. The outer jacket material is of utmost importance for this purpose.

It is subject to demanding requirements: Protection class IP66 / IP68, aging tests against embrittlement by environmental effects (temperature and humidity) and impact testing with 7J without cracking. The surface resistance of all components (corrugated pipe, silicone caps) must not exceed 10^9 Ohm (electrostatically dissipative).

The corrugated pipes and silicone caps used in Winkler ATEX heated lines and heated hoses all meet these requirements. Another important feature for a safe and intended operation is appropriate protection against chemical effects, the efficiency of which mainly depends on temperature, exposure time (prolonged exposure or short contact) and concentration of the chemical

Conclusion

The safety-relevant requirements for electric heating in potentially explosive atmospheres are diverse and extensive. Therefore, the development of process-specific heating systems requires intensive care including the addressing of predictable errors beforehand by means of appropriate design measures. Restrictions in installation and operating manuals should be avoided. Application- and process-independent design becomes more and more important. A product is truly safe and efficient when it has passed a system-wide inspection.

The system inspection should – besides considering all eventualities for potentially explosive areas – include experience and knowledge derived from other application types.
Today's requirements on materials used in ATEX products actually demand a complete system inspection in order to guarantee safe and intended operation – especially in changing operating conditions.

Literature

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[3] DIN EN 13463-1 : Non-electrical equipment for use in potentially explosive atmospheres – Part 1: Basic methods and requirements (Beuth Verlag, Berlin).
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[5] DIN EN 13980:2003-02 Potentially explosive atmospheres – Applications for Quality Management Systems (Beuth Verlag, Berlin)
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[8] DIN EN 60079-ff (Beuth Verlag, Berlin)
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