

Co-Design of Electrical Infrastructure and Environmental Containment in Food Processing and Chemical Storage Facilities: An Engineering Safety Framework

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Abstract- Modern industrial facilities have to meet a complicated combination of regulatory compliance requirements. Since food safety regulations require thorough sanitization, the separation of raw materials, and the use of dedicated stores for hazardous chemicals in order to avoid both biological and chemical contamination, these environmental controls bring about considerable difficulties for the electrical infrastructure. The presence of high-pressure chemical washdowns, corrosive atmospheres, and explosive vapours in locked storage areas increases the likelihood of electrical faults, insulation failure, and arc flash incidents.

The paper addresses the gap between hygiene and chemical containment regulations and electrical safety engineering. Having examined the standard sanitization requirements, it develops an engineering safety framework which assigns specific electrical protection methods to different environmental zones (for example, Ingress Protection, NEMA classifications, and Hazardous Area zoning as defined by IEC 60079 / NEC Article 500). The paper suggests a unified design approach in order to reduce degradation, avoid contamination, and ensure high-reliability electrical safety in severe industrial environments.

Indexed Terms- National Electrical Code (NEC), IEC 60079, Industrial Electrical Safety, Ingress Protection (IP69K), Hazardous Locations, Chemical Segregation, Food Safety Regulations, Corrosion Mitigation.

I. INTRODUCTION

In industrial processing, especially in the food, beverage and chemical industries, regulatory rules tend to work by themselves. The food safety rules—for example, those which call for raw materials to be kept separate from finished products and for cleaning chemicals to be stored in a dedicated and secure manner—are mainly intended for the protection of consumers and to avoid cross-contamination.

From the point of view of electrical engineering, these environmental conditions constitute highly aggressive and non-standard operating environments.

The need for frequent washdowns to avoid biological buildup exposes the electrical enclosures, conduits, and sensor networks to high-pressure, high-temperature water jets that contain corrosive surfactants.

In corrosive and gaseous environments, secure areas for the storage of chemicals often end up with volatile organic compounds (VOCs), vapours which are acidic or alkaline, and a high level of relative humidity, all of which greatly speed up the corrosion of electrical metallic tubing (EMT), the grounding paths, and the terminal connections.

The paper presents an academic and practical framework for the co-design of industrial facilities, making it possible to meet the physical layout requirements set by hygiene standards without compromising electrical safety, system reliability, or personnel protection.

II. THE ENGINEERING PROBLEMS IN ENVIRONMENTS WHERE PEOPLE ARE SEGREGATED

Regulatory guidelines show that industrial spaces are split into strict functional zones. Each zone needs a different electrical design.

Table 1: Mapping of Processing Zones to Electrical Hazards and Design Responses

Processing Zone / Requirement

Dominant Environmental Stressor

Primary Electrical Risk

Engineering Mitigation

Raw Material & Processing Area (High Hygiene/Washdown)

Water under high pressure, as well as alkaline or acidic sanitizers, and high humidity.

Moisture entering, failure of the tracking index, deterioration of the insulation, short circuits.

IP69K or NEMA 4X enclosures. Food-grade stainless steel (316L) conduits. Non-metallic materials.

Finished Product Storage (Dry/Climate Controlled)

Dust builds up. Transport equipment causes mechanical impact.

Ignition by dust (Class II), damage to cable trays due to physical causes.

Rigid metal conduits (RMC), enclosures which are dust-ignitionproof (IP6X / Class II, Div 1).

Chemical & Cleaning Agent Storage (Locked/Secure)

Corrosive outgassing. Possible explosive vapors from flammable solvents.

The grounding circuits are subject to chemical corrosion and may be ignited by an explosive atmosphere (Class I / Zone 1).

Installations that are intrinsically safe (Ex i) or flameproof (Ex d) should have continuous ventilation interlocking.

III. INGRESS PROTECTION (IP) AND MATERIAL DEGRADATION IN AREAS SUBJECT TO WASH-DOWNS

The need for continuous "maintenance and cleaning" in order to "prevent contamination" generally leads to the adoption of washdown procedures involving high-pressure water jets.

3.1 The physics behind ingress protection (IP69K)

Standard industrial electrical enclosures of IP65/IP66 rating are not adequate for use in modern food processing washdowns, since in order to endure high-pressure cleaning the systems have to meet the IP69K

standard (as defined by ISO 20653 / IEC 60529), which tests the enclosure's resistance to high-pressure water jets:

Water Pressure: \$8,000 \text{ to } 10,000 \text{ kPa}\$ (\$80 \text{ to } 100 \text{ bar}\$)

Water Temperature: \$80^{\circ}\text{C}\$

Flow Rate: \$14 \text{ to } 16 \text{ L/min}\$

The angles of impact are 0 degrees, 30 degrees, 60 degrees, and 90 degrees relative to the vertical plane.

3.2 The occurrence of galvanic and chemical corrosion on enclosures

The use of ordinary carbon steel or basic aluminum in areas where chemicals are stored or cleaned results in quick oxidation, which damages the enclosure's structural integrity and its ground continuity. The rate of uniform chemical corrosion on a metal surface area (R) can be expressed as:

$$R = \frac{W}{A \cdot t \cdot \rho}$$

Where:

W is the weight loss of the metal (g)

A is the exposed surface area (cm²)

t is the exposure time (hours)

ρ is the density of the metal (g/cm³)

In places where cleaning agents are stored the local relative humidity and the concentration of chemical vapours rise exponentially with R. It is therefore necessary for electrical engineers to specify Type 316 Stainless Steel (UNS S31600), this steel containing 2 to 3% molybdenum in order to prevent pitting corrosion resulting from chloride-based sanitizers.

IV. DESIGNING FOR ELECTRICAL SAFETY IN THE STORAGE OF HAZARDOUS CHEMICALS

The requirement for a "separate, and where necessary, securely (by means of being locked or otherwise access controlled) stored" area for cleaning materials and hazardous substances results in the formation of

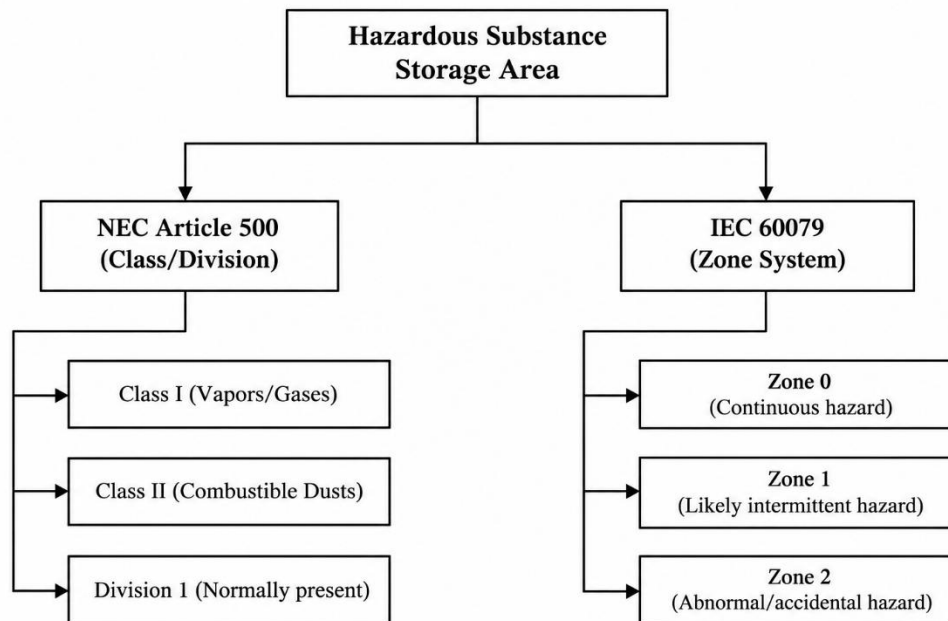
highly concentrated micro-climates of explosive or corrosive vapours.

4.1 Zone Classification (NEC vs. IEC)

The NEC and IEC use different systems for classifying hazardous locations. The NEC uses Divisions and Classes, while the IEC uses Zones and Groups. In the NEC system, Division 1 means the hazard is likely to be present during normal operation, and Division 2 means the hazard is not likely to be present under normal conditions. The IEC system uses Zone 0, Zone 1, and Zone 2. Zone 0 is where an explosive atmosphere is present all the time or for long periods.

Zone 1 is where it is likely to occur during normal operation. Zone 2 is where it is not likely to occur, and if it does, it will only last for a short time. Both systems aim to keep people and equipment safe in areas with flammable gases, vapors, or dusts, but they use different terms and criteria.

To prevent electrical arcs, sparks, or high temperatures from acting as an ignition source, these storage facilities must be strictly classified under hazardous area standards:



When flammable solvents or cleaning chemicals (such as isopropyl alcohol and certain peroxides) are stored, the area should be classified as Class I, Division 1 (or Zone 1).

4.2 Protection Methodologies

For electrical equipment operating inside secure chemical storage areas, the following explosion protection concepts must be applied:

Intrinsically safe (Ex "i" / IEC 60079-11): it ensures that the thermal and electrical energy in the circuit is below the minimum ignition energy (MIE) of the

surrounding gas mixture. It is essential for use with instrumentation, security access-control panels, and sensors.

Flameproof/Explosionproof (Ex "d" / IEC 60079-1): these enclosures are constructed in such a way that an explosion inside them does not cause the flame to spread into the surrounding hazardous atmosphere. Their use is strongly advised for power distribution boards and for high-power motor switches located in areas involved in chemical transfer.

V. SUGGESTED HARMONIZED ENGINEERING FRAMEWORK

To successfully integrate facility hygiene regulations with international electrical safety standards (such as NFPA 70, IEEE 1584, and IEC 60364), design teams must implement a structured, cross-disciplinary workflow:

[Step 1: Facility Zoning Layout]

- | (Identify washdown boundaries, chemical storage, and dry areas)



[Step 2: Environmental Boundary Assessment]

- | (Define chemical exposure, washdown pressures, and temperature profiles)



[Step 3: Hazardous Area Classification]

- | (Perform Gas/Dust/Vapor dispersion analysis; map Zone 1/2 or Div 1/2 boundaries)



[Step 4: Electrical Infrastructure Specification]

- | (Select IP69K/NEMA 4X hardware, Ex-certified gear, and 316L SS conduit networks)



[Step 5: Safety Validation & Maintenance Protocol]

- | (Formulate thermal imaging, insulation resistance testing, and ground-loop monitoring)

Key Engineering Practices:

For the safe storage of chemicals, the operation of the exhaust fans must be electrically interlocked with that of the lighting and the power distribution system; if ventilation fails, power in the non-essential electrical circuits must automatically be cut off in order to prevent the ignition of any accumulated gases.

All circuits which pass through washdown and chemical containment areas must be protected by

highly sensitive Residual Current Devices (RCDs) with a trip threshold of $\leq 30 \text{ mA}$ (or by Class A GFCIs having a $4\text{-}6 \text{ mA}$ threshold for the purpose of protecting personnel) in order to counter the greater shock hazard caused by wet floors.

VI. CONCLUSION

There is no need for rigorous industrial safety and contamination controls to be achieved at the cost of the integrity of the electrical infrastructure; electrical engineers will be able to apply specific and resilient solutions by treating the cleanrooms, the areas where the raw materials are processed, and the locked chemical stores as separate environmental micro-climates.

Using high-grade materials such as 316L stainless steel, strictly observing IP69K ratings in areas subject to washdowns, and applying accurate hazardous area classifications (Class I, Div 1 / Zone 1) when storing chemicals ensures long-term facility safety, continuous compliance with regulatory requirements, and maximum operational uptime.