ELECTROSTATIC HAZARDS
ASSOCIATED WITH
POWDER AND LIQUID HANDLING

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CHIEF TECHNICAL OFFICER - PROCESS SAFETY
Presentation Outline

• Management of Flash Fires and Explosions

• A Systematic Approach to Electrostatic Hazard Assessment
  » Charge Generation
  » Charge Accumulation
  » Discharges
  » Laboratory Measurements

• Control of Electrostatic Hazard
  » Metal (Conductive) Items
  » People
  » Non-Conductive (Insulating) Materials
  » Liquid Handling
  » Powder Handling
  » Flexible Intermediate Bulk Containers (FIBCs)
Where flammable gases and vapors, combustible dusts, and reactive chemicals are processed, handled, and/or generated, fire, explosion, and/or runaway chemical reaction hazards can occur.

These hazards can lead to catastrophic events involving injuries, fatalities, environmental impact, production losses, and facility damage.

In the US alone, each major industrial incident costs an average of $80 million.

Largely as a result of the disastrous incidents in Seveso, Italy in 1976 and Bhopal, India in 1984, a number of systems for the management of process safety have been developed and implemented, including:

- Early CCPS process safety management model (1989),
- Responsible Care code (late 1980’s),
- OSHA PSM (1992),
- EU’s Seveso I, II, and III directives,
- CCPS 2007 risk-based PSM model,
- Numerous company-specific approaches.

Although most chemical companies have adopted one or more versions of these models, serious and catastrophic incidents continue to occur each year.
# PROCESS SAFETY MANAGEMENT ELEMENTS

<table>
<thead>
<tr>
<th>Work Stream</th>
<th>CCPS Element</th>
</tr>
</thead>
</table>
| 1 Incident response| 1. Stakeholder outreach  
                               2. Emergency management  
                               3. Incident investigation |
| 2 Risk Management  | 1. Hazard identification and risk analysis                        |
| 3 Operations       | 1. Operating procedures  
                               2. Safe work practices  
                               3. Operational readiness  
                               4. Contractor management |
| 4 Asset integrity  | 1. Asset integrity & reliability  
                               2. Management of change |
| 5 Accountability   | 1. Measurement & metrics  
                               2. Auditing  
                               3. Management review & continuous improvement |
| 6 Capability       | 1. Compliance with standards  
                               2. Process knowledge management  
                               3. Process safety competency  
                               4. Training & performance assurance |
| 7 Culture          | 1. Process safety culture  
                               2. Workforce involvement  
                               3. Conduct of operations – operational discipline |
EFFECTIVE RISK-BASED PSM COMPLIANCE
Gluing Process Safety Management Elements Together

- Organizational Culture
- Organizational Capability
- Risk Management
- Operations
- Incident response
- Asset Integrity
- Accountability
EFFECTIVE RISK-BASED PSM COMPLIANCE

• A three pronged approach to effective PSM:
  1. Sound process safety management systems
  2. There must be a competency established within the organization based on education, training, and experience in the related process safety areas,
  3. A safety culture must be in place that starts at the top and trickles down to the shop floor level,

  ➢ Experience has shown that unless safety programs are supported by the highest levels of management, they are more than likely to fail,
FIRE TRIANGLE

- **FUEL** - Liquid (vapor or mist), gas, or solid capable of being oxidized. Combustion always occurs in the vapor phase; liquids are volatized and solids are decomposed into vapor prior to combustion.
- **OXIDANT** - A substance which supports combustion – Usually oxygen in air.
- **IGNITION SOURCE** - An energy source capable of initiating a combustion reaction.
MANAGEMENT OF FLASH FIRE AND EXPLOSION HAZARDS

- Understanding flammability, electrostatic, and explosion characteristics of the fuel(s)
- Understanding processes, operations, and review of all available information (drawings, specifications, process/operation descriptions)
- Identification of locations where flammable atmospheres (gas, vapor, dust) are or could be present during normal and abnormal operating conditions
- Identification of potential ignition sources that could be present under normal and abnormal conditions
- On-site electrostatic measurements (electrical field, electrical continuity measurements, etc.), where applicable
- Proper process and facility design to prevent and/or minimize the occurrence of flash fires and explosions and protect people and facilities against their consequences
- Regular inspection and maintenance of equipment to minimize ignition sources and fuel releases
TYPICAL IGNITION SOURCES

• Personal smoking materials
• Hot work
• Open flames
• Mechanical friction and sparks
• Impact sparks
• Hot surfaces and equipment
• Thermal decomposition
• Electrical equipment
• Electrostatic discharges
# Codes and Standards Related to Static Electricity

<table>
<thead>
<tr>
<th>Document</th>
<th>Country/Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Fire Protection Association (NFPA) 77 (2013)</td>
<td>USA</td>
</tr>
<tr>
<td>CLC/TR 50404 (2003), CENELEC</td>
<td>EU (superseded / withdrawn)</td>
</tr>
<tr>
<td>Energy Institute Model Code of Safe Practice - Part 21</td>
<td>Industry guidance aimed at the energy industry</td>
</tr>
<tr>
<td>BS 5958-1: 1991</td>
<td>BSI, current, superseded</td>
</tr>
<tr>
<td>IEC 61340-4-4, 2.1 Edition, 2014-11</td>
<td>IEC</td>
</tr>
<tr>
<td>Britton, L. G.; Book Published by Wiley - AIChE, 1999</td>
<td></td>
</tr>
<tr>
<td>Vahid Ebadat, et al., Chapter 36, Handbook of Chemical Health &amp; Safety, Oxford University Press, 2001</td>
<td></td>
</tr>
</tbody>
</table>
ELECTROSTATIC HAZARD ASSESSMENT

- Charge Generation
- Charge Accumulation
  - Isolated Conductors
  - Insulating Objects
  - People
  - Liquids
  - Powders
- Incendivity of Discharges
- Sensitivity of the Atmosphere to Ignition

Schematic of a Typical Chemical Plant

- Tank farm
- Centrifuge
- Vacuum Dryer
- Mill
- Reactor
Electrostatic charges are usually generated when any two materials make and then break contact, with one becoming negative and the other positive.

Magnitude and polarity of the charge depends on many factors, including:

- Nature of the contacting surfaces
- Actual contact area
- Speed and type of contact and separation

![Diagram showing positive charges fixed on material and negative charges at the interface with no net charge.](image)
ELECTROSTATIC CHARGE GENERATION - CONTACT

Examples

» Powder handling
  o Pouring
  o Sieving
  o Mixing
  o Milling
  o Pneumatic transfer

» Liquid handling
  o Liquid transfer through hoses and pipes
  o Agitation of two phase mixtures
  o Settling of two phase mixtures
  o Filtration

Schematic of a Typical Chemical Plant
• An isolated electrical conductor in an electric field acquires a potential on its surface. This initiates a current in the conductor which continues until its field is reduced to zero. Some of the free electrons travel in the direction of the positive pole of the field. On the opposite side of the body excessive positive charges are fixed by the negative charges from the opposing pole of the field.

• If the charges of one sign are eliminated by connecting one end to ground while the body is in the field the body is charged upon removal from the field.
ELECTROSTATIC CHARGE GENERATION

• Electrostatic charge generation will only result in a discharge if charge is allowed to build up on surfaces/materials
• Build up of charge on the following types of surfaces/materials can give rise to electrostatic discharges:
  » Electrostatically Isolated Conductors
  » Electrostatically Insulating Objects
  » Non-Conductive Liquids
  » Insulating Powders
• Ignition occurs if discharge energy is greater than the Minimum Ignition Energy of the flammable atmosphere
Incendivity (igniting power) of electrostatic discharges depend on resistivity and the geometric arrangement of the charged object and the geometry of the discharge initiating electrode:

- **Discharge Between Two Conductive Objects at Different Potentials (Spark Discharge)**
  - Stored (Spark) Energy = $\frac{1}{2} CV^2$

- **Discharge Between a Conductor and an Insulator (Brush Discharge)**
  - Maximum discharge energy of 4mJ

- **Discharge on the Surface of an Insulator Backed by a Conductor or inside surface of an insulating pipe (Propagating brush Discharge)**
  - A surface coated with a thin layer of an insulating material will act as a capacitor to store charge

- **Discharges During Filling Powders into Containers (Bulk/Cone Discharge)**
  - Bulking discharges have a maximum effective energy of about 25mJ and occur during the filling of vessels with insulating powders
ELECTROSTATIC CHARACTERISTICS OF MATERIALS AND PLANT

- The first step in assessing electrostatic problems and hazards is to establish the electrostatic properties of the materials processed, handled, and/or used in the plant
  - **Minimum Ignition Energy** of flammable atmospheres
  - **Resistance-to-Ground** of conductive (metal) objects and items of plant
  - **Electrical Resistance** of operators’ footwear and floors
  - **Electrostatic Chargeability** of powders and liquids (alternatively, measure surface voltage or electric field during processing)
  - **Volume Resistivity** of powders
  - **Conductivity** of liquids
  - **Surface Resistivity** of solid objects such as plastic containers and liners
MINIMUM IGNITION ENERGY (MIE) - ASTM E2019 / IEC 61241-2-3 (PART 2, SECTION 3) / BS EN 13821:2002

- MIE of a flammable material is the smallest electrostatic spark energy needed to ignite an optimum concentration of the material using a capacitive spark

Minimum Ignition Energy Circuit
### FACTORS AFFECTING MINIMUM IGNITION ENERGY

<table>
<thead>
<tr>
<th>Some Influencing Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing Particle Size</td>
</tr>
<tr>
<td>Increasing Moisture Content</td>
</tr>
<tr>
<td>Presence of Flammable Vapor (even if below LFL)</td>
</tr>
<tr>
<td>Increasing Ambient Temperature</td>
</tr>
<tr>
<td>Inductance of Discharge Circuit</td>
</tr>
</tbody>
</table>

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## TYPICAL MINIMUM IGNITION ENERGY VALUES

<table>
<thead>
<tr>
<th>Atmosphere</th>
<th>Material</th>
<th>Minimum Ignition Energy (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapor / Gas</td>
<td>PROPANOL</td>
<td>0.650</td>
</tr>
<tr>
<td></td>
<td>ETHYLE ACETATE</td>
<td>0.460</td>
</tr>
<tr>
<td></td>
<td>METHANE</td>
<td>0.280</td>
</tr>
<tr>
<td></td>
<td>PROPANE</td>
<td>0.250</td>
</tr>
<tr>
<td></td>
<td>ETHANE</td>
<td>0.240</td>
</tr>
<tr>
<td></td>
<td>METHANOL</td>
<td>0.140</td>
</tr>
<tr>
<td></td>
<td>ACETYLENE</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td>HYDROGEN</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>CARBON DISULPHIDE</td>
<td>0.009</td>
</tr>
<tr>
<td>Dust Cloud</td>
<td>PVC</td>
<td>1,500</td>
</tr>
<tr>
<td></td>
<td>ZINC</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>WHEAT FLOUR</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>POLYETHYLENE</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>SUGAR</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>MAGNESIUM</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>SULPHUR</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>ALUMINIUM</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>EPOXY RESIN</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>ZIRCONIUM</td>
<td>5</td>
</tr>
</tbody>
</table>

- Describes ability of a material (powder) to retain/dissipate electrostatic charges
- Is a property of material itself, regardless of the dimensions of the sample
- Can be influenced by moisture content of powder
- Is related to resistance, R, measured when a voltage is applied across it, by following equation

Volume Resistivity, \( p_v = \frac{R \cdot A}{d} \)

- \( A \) is the sample area and \( d \) its length
- Unit of Volume Resistivity is Ohm meters (\( \Omega \cdot m \))
## Classification of Materials by Their Volume Resistivity

<table>
<thead>
<tr>
<th>Resistivity (Ohm.m)</th>
<th>Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10^6</td>
<td>Low Resistivity (Conductive)</td>
<td>Metals</td>
</tr>
<tr>
<td>10^6 to 10^9</td>
<td>Medium Resistivity (Semi-Conductive)</td>
<td>Some organic powders, Concrete, wood</td>
</tr>
<tr>
<td>&gt;10^9</td>
<td>High Resistivity (Insulating)</td>
<td>Synthetic polymers</td>
</tr>
</tbody>
</table>
ELECTROSTATIC CHARGEABILITY - ASTM D257

- Chargeability refers to propensity of a material (solid or liquid) to become charged when flowing through conveyances or when handled in containers.
- Measured by flowing test sample through tubes of uniform length and made from different materials -- specifically stainless steel, plastic, and glass -- and measuring the resultant electrostatic charge.
- Test data is used to develop appropriate materials handling guidelines.
ELECTROSTATIC CHARGEABILITY - ASTM D257

• Typical Mass Charge Densities ($\mu$C/kg) for Medium Resistivity Powders

<table>
<thead>
<tr>
<th>Process</th>
<th>Min. Value</th>
<th>Max. Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieving</td>
<td>$1\times10^{-5}$</td>
<td>$1\times10^{-3}$</td>
</tr>
<tr>
<td>Pouring</td>
<td>$1\times10^{-3}$</td>
<td>$1\times10^{-1}$</td>
</tr>
<tr>
<td>Screw Feeding</td>
<td>$1\times10^{-2}$</td>
<td>$1$</td>
</tr>
<tr>
<td>Grinding</td>
<td>$1\times10^{-1}$</td>
<td>$1$</td>
</tr>
<tr>
<td>Micronizing</td>
<td>$1\times10^{-1}$</td>
<td>$1\times10^{2}$</td>
</tr>
<tr>
<td>Pneumatic Conveying</td>
<td>$1\times10^{-1}$</td>
<td>$1\times10^{3}$</td>
</tr>
</tbody>
</table>
SURFACE RESISTIVITY – BS 7506, IEC 61340 PART 2/PART 3, GENERAL ACCORDANCE OF ASTM D257

• Describes the ability of a solid surface to transmit electric charges
• Is measured by applying a voltage between parallel electrodes placed on the surface so that the spacing between the electrodes is equal to their length
• Provided the electrode spacing and length remain equal, the same resistance is measured, whatever the dimensions chosen
• Units of Surface Resistivity are Ohm/square
• Material is considered insulating if Surface Resistivity $>10^{11}$ ohm/square
LIQUID CONDUCTIVITY - BS 5958 PART 1, BS EN 60247 PART 2

- Describes the ability of a liquid to retain electrostatic charge
- Conductivity is calculated by:

\[ \sigma = k \frac{I}{V} \]

Where:
- \( \sigma \) is the electrical conductivity (S/m)
- \( k \) is the cell constant (m\(^{-1}\))
- \( I \) is the measured current (A)
- \( V \) is the applied potential difference (V)
- Unit of conductivity is Siemens/meter
## LIQUID CONDUCTIVITY

- Classification of Liquids by their Conductivity

<table>
<thead>
<tr>
<th>Conductivity Level</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Conductivity</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Medium Conductivity</td>
<td>100 - 10,000</td>
</tr>
<tr>
<td>High Conductivity</td>
<td>&gt;10,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conductivity pS/m</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;100</td>
<td>Toluene</td>
</tr>
<tr>
<td>100 - 10,000</td>
<td>Isopropyl Ether</td>
</tr>
<tr>
<td>&gt;10,000</td>
<td>Acetone</td>
</tr>
</tbody>
</table>
CONTROL OF ELECTROSTATIC HAZARDS - CONDUCTIVE OBJECTS

• Electrostatic charge can accumulate on electrically isolated conductive (metal) plant and give rise to spark discharges
• Charge accumulation occurs if resistance-to-ground is greater than 1MΩ
• Spark energy depends on metal object’s capacitance and magnitude of static charge that accumulates on it
• Resistance to ground should be checked.
• If R>10 ohm, direct ground connection is required
  » Grounding connections should be routed to protect them from accidental damage
  » Their purpose should be known to operators
  » Fixings for ground connections should be clearly visible
CONTROL OF ELECTROSTATIC HAZARDS - INSULATING OBJECTS

- Non-conductive materials such as plastic containers and liners can become electrostatically charged by manual rubbing causing “Brush” discharges.
- Pneumatic conveying of powders through non-conductive (plastic) hoses and pipes can highly charge the inside surfaces of the hose/pipe giving rise to “Propagating Brush” discharges.
- Highly charged liquids and powders entering non-conductive containers/liners can charge the inside surfaces of the container/liner causing “Propagating Brush” discharges.
- Charge retention on powders and liquids in non-conductive containers.
- Grounding of non-conductive materials would not facilitate the relaxation of electrostatic charges to ground.
- Use conductive or static dissipative materials with a Surface Resistivity less than $10^{11}$ Ohm/Square.
Internal metal spiral to ensure electrical continuity and shielding
CONTROL OF ELECTROSTATIC HAZARDS - LIQUIDS

- Static electricity hazards can arise in various liquid handling operations including filling, sampling, filtration and mixing. The following suggestions can reduce the electrostatic ignition hazards.

  » **Use Electrically Grounded Conductive Plant**
    
    All items of plant including pipes, vessels, containers etc. should be electrically conductive and/or static dissipative and grounded.

  » **Increase Liquid Conductivity**
    
    An antistatic additive may be used in very small concentrations in order to raise the liquid conductivity.

  » **Filters and Valves**
    
    Use valves with maximum diameter possible. Locate filters and valves as far as possible from the entrance to the receiving vessel.
CONTROL OF ELECTROSTATIC HAZARDS - LIQUIDS

- Static electricity hazards can arise in various liquid handling operations including filling, sampling, filtration and mixing. The following suggestions can reduce the electrostatic ignition hazards.

  » Control of Liquid Entry to the Vessel
    Liquid should enter a vessel through a dip leg with submerged ends or bottom inlet point

  » Control of Flow Velocity
    - Liquids with conductivity > 100pS/m, no flow velocity restrictions
    - Liquids with conductivity < 100pS/m and no immiscible components, flow velocity should be less than 7m/s
    - Liquids with conductivity < 100pS/m and containing immiscible components, flow velocity should be less than 1m/s
CONTROL OF ELECTROSTATIC HAZARDS - PERSONNEL

- Electrostatic charge can accumulate on personnel isolated from ground through the use of insulating footwear and/or standing on insulating surfaces
- Personnel can typically attain potentials of 10 to 15kV
- Maximum discharge energy 20mJ to 30mJ
- Personnel should be grounded so that their resistance-to-ground <1x10⁸ ohm
- Static dissipative footwear may be used
- Resistance of the floor/surface on which the operator is standing should also be <1x10⁸ ohm
CONTROL OF ELECTROSTATIC HAZARDS - POWDERS

Control of “Bulk”/“Cone” discharges on powder surface during filling of vessels/ bins/ containers:

- **Volume Resistivity < 10^9 Ohm.m**
  - No electrostatic charge accumulation and hence on “Bulk” discharge if powder is handled in grounded conductive plant

- **Volume Resistivity > 10^9 Ohm.m and Minimum Ignition Energy >25mJ**
  - No electrostatic ignition hazard in grounded conductive plant

- **Volume resistivity > 10^9 Ohm.m and Minimum Ignition Energy <25mJ**
  - If Electrostatic Chargeability test results show that the quantity of electrostatic charge on particles is sufficient to cause discharges from surface of bulking powder consider:
    - Installation of inert gas blanketing, or
    - Installation of explosion protection

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CONTROL OF ELECTROSTATIC HAZARDS - FIBCS

• Applicable Standard:
CONTROL OF ELECTROSTATIC HAZARDS - FIBCS

• Four Types of FIBCs:
  » **Type A**  Made from fabric or plastic sheet without any measures against the buildup of static electricity
  » **Type B**  Constructed from insulating fabric or plastic sheet designed to prevent “Sparks” and “Propagating Brush Discharges”
  » **Type C**  Design relies on grounding to prevent electrostatic hazards
  » **Type D**  Constructed from fabrics with static protective threads and/or properties to control discharge incendivity without earthing
## USE OF DIFFERENT TYPES OF FIBC - IEC 61340-4-4, EDITION 2.1, 2014-11

<table>
<thead>
<tr>
<th>Bulk Product in FIBC</th>
<th>Surroundings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MIE of Dust</td>
</tr>
<tr>
<td></td>
<td>MIE &gt; 1,000mJ</td>
</tr>
<tr>
<td></td>
<td>3mJ &lt; MIE &lt; 1,000mJ</td>
</tr>
<tr>
<td></td>
<td>MIE ≤ 3mJ</td>
</tr>
</tbody>
</table>

1. Additional precautions are usually necessary when a flammable gas or vapor atmosphere is present inside the FIBC, e.g. in case of solvent wet powders
2. Non-flammable atmosphere includes dusts having a MIE > 1,000mJ
3. Use of Type D FIBCs shall be limited to atmospheres with MIE ≥ 0.14mJ
If water vapor is present in air, it absorbs onto surfaces and forms a slightly conducting surface layer.

The extent to which the water absorbs and the increase in conductivity depends on the nature of the surface and the humidity of the atmosphere.

Although there is not a definitive relative humidity where the conductivity of all materials changes, holding the relative humidity at about 65% may significantly reduce electrostatic effects without introducing an unpleasant environment.
Thank you!

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