Static Ignition Hazards
When Handling Petroleum Products

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Introduction

Static electricity in one form or another is a phenomenon of nature and often results in electrostatic discharges that can cause fires and explosions. While expertise to reduce these hazards is based on research, in addition there is much industry experience upon which to base safety precautions when handling petroleum liquids. This is a two-part paper. Part 1 addresses a basic understanding of static electricity and commonly used precautions used in the operation of vehicle fueling facilities, tank vehicles, storage tanks, aviation facilities, and miscellaneous hazards. Part 2 addresses a basic understanding of lightning, stray currents, commonly used protection against such spark promoters, and includes a list of references for further study.

Published Research

Static ignition research has been sponsored by such organizations as the American Gas Association, U. S. Department of the Interior, Bureau of Mines, U. S. Air Force and the petroleum industry. This research is embodied in recommendations for protection against static ignition in publications and videos produced by these and other organizations, such as the American Petroleum Institute and National Fire Protection Association. However, many of these recommendations are based on years of practical operating experience in the petroleum industry.

Part 1. Static Electricity

I. Static Electric Generation

Introduction: Electricity was first observed as a phenomenon of nature when small sparks were observed with some materials that were rubbed with silk or wool. Later, when electricity was found to move freely through conductors, the term static came about to describe electricity that was trapped on a body that was said to be charged.

A static electrical charge may be either positive (+) or negative (-) and is manifested when some force has separated the negative electrons from the positive protons of an atom. Typical forces include flowing, mixing, pouring, pumping, filtering or agitating materials where there is the forceful separation of two like or unlike materials. Examples of static generation are common with operations involving the movement of liquid hydrocarbons, gases contaminated with particles (e. g., metal scale and rust), liquid particles (e. g., paint spray, steam) and dust or fibers (e. g., drive belts, conveyors). The static electric charging rate is increased greatly by increasing the speed of separation (e. g., flow rate and turbulence), low conductivity materials (e. g., hydrocarbon liquids) and surface area of the interface (e. g., pipe or hose length, and micropore filters).

II. Static Electric Accumulation

Electrostatic charges typically leak from a charged body because they are under the attraction of an equal but opposite charge. Thus, most static sparks are produced only while the generating mechanism is active. However, some refined petroleum products have insulating qualities and the charges generated during movement will remain for a short period of time after the product has stopped moving. This accumulation, rather than dissipation, is influenced by how well the bodies are insulated with respect to each other. Since air or air/vapor mixtures are often the insulating body between the opposite charges, both temperature and humidity are factors in this insulation. Thus, very low or high temperatures, with resulting low humidity, will increase the accumulation of the electrostatic charge both while it is being generated and during the normal relaxation period.

III. Spark Gap

A spark results from the sudden breakdown of the insulating strength of a dielectric (e. g., air) that separates two electrodes of different potentials. This breakdown produces a flow of electricity across the spark gap and is accompanied by a flash of light, indicating high temperature. For static electricity to discharge a spark, the voltage across the gap must be above a certain magnitude. In air, at sea level, the minimum sparking voltage is approximately 350 volts for the shortest measurable gap. The voltage required will vary with the dielectric strength of the materials (e. g., air, and vapor) that fill the gap and with the geometry of the gap.

IV. Flammability of Vapor-Air Mixtures

The flammability of a hydrocarbon vapor-air mixture depends on its vapor pressure, flash point and temperature. These properties are used to classify petroleum products whose electrical resistivities are high enough to enable them to accumulate significant electrostatic charges under certain handling conditions. Following are the three petroleum product Vapor Pressure Classifications, including common examples:

Low – Those with a closed cup flash point above 100°F (38°C).

These products do not develop flammable vapors under normal handling conditions. However, conditions for ignition may exist, if handled at temperatures above their flash points, are contaminated with higher vapor-pressure materials, or are transferred into containers where vapors are at concentrations at or above those necessary to produce a flammable mixture.

Examples: #2 Fuel Oil; Kerosene, Diesel, Jet Fuel A (commercial), Motor Oil, Asphalt, and Safety Solvents

Intermediate – Those with a closed-cup flash point below 100°F (38°C).

These products may create a flammable mixture in the vapor space at ambient temperatures.

Examples: Xylene, Benzene, Toluene, Jet B (commercial), JP-4 (military), and Stoddard Solvents

High – Those with a Reid Vapor pressure above 4.5 psi absolute (31 kilopascals).

These products, under normal handling temperatures in a closed vapor space, will rapidly produce a mixture too rich to be flammable. However, in some areas, a vapor space may pass through the flammable range before becoming too rich.

Examples: Motor and Aviation Gasoline's, and high vapor pressure Naphtha's

V. Ignition by Static Electricity

As a result, once a means of generating and accumulating an electrostatic charge exists, it will be a source of ignition under the following three conditions:

1. The accumulated electrostatic charge is capable of producing an incendiary spark.
2. There is a spark gap.
3. There is an ignitable vapor-air mixture in the spark gap.

VI. Control of Ignition Hazards

A. Reducing Static Generation

Static charge voltage may be prevented from reaching the sparking potential by reducing the rate of static generation. In the case of petroleum products, decreasing the activities that produce static can reduce the rate of generation. Since static is generated whenever two dissimilar materials are in relative motion to each other, a slowing down of this motion will reduce the rate of generation. This means reducing agitation by avoiding air or vapor bubbling, reducing flow velocity, reducing jet and propeller blending, and avoiding free falling liquid. However, such static control methods may not be commercially acceptable because of slower production. Thus, reducing or rapidly dissipating the charge by bonding or grounding is commonly used to reduce static electricity.

B. Increasing Static Dissipation

Bonding and Grounding: Sparking between two conducting bodies can be prevented by means of an electrical bond attached to both bodies. Bonding prevents the accumulation of a difference in potential across the gap, thus no charge can accumulate and no spark can occur. The earth may be used as part of the bonding system. This is known as grounding and is used when a potentially electrically charged body is insulated from the ground. Thus, the ground connection bypasses this insulation.

Anti-static Additives: Since the dissipation of the static charge is a function of the liquid's conductivity, anti-static additives may be used. These additives do not reduce static generation, but will permit the charge to dissipate more quickly. They should be introduced at the distribution beginning point and their effectiveness may be reduced by passage through clay filters.

C. Controlling the Environment

Inerting and Ventilation: When static discharge cannot be avoided by bonding, grounding, reducing static generation, or increasing static dissipation, ignition can be prevented by excluding ignitable vapor-air mixtures where sparks may occur. Two commonly used methods are inerting and mechanical ventilation. Inerting is a method of displacing the air with an inert gas to make the mixture nonflammable. Mechanical ventilation can be applied to dilute the ignitable mixture well below the flammable range.

VII. Vehicles, Storage Tanks, Containers and Piping

Following is a discussion of common static electricity problem areas found in petroleum distribution and fuel handling facilities, and precautions to be taken.

A. Highway and Aviation Transport Vehicles

Static from vehicle motion may be generated by the separation of air and dust particles on the vehicle surface, the separation of the tires from the pavement and agitation of intermediate vapor pressure products when the tank or compartment is not full. It has been found that drag chains do not effectively bond the vehicle to the pavement since paved surfaces are insulated when dry and bonding is not needed when wet. Thus, static charges may be transported from one place to another, and a dissimilar electric potential may exist between the vehicle and loading or unloading facility.

Before tank loading begins, the truck is bonded to the loading facility, which in turn is grounded. Whether top or bottom loaded, splashing or spraying should be avoided by limiting the filling velocity to 3 feet per second until the loading outlet is submerged.

When tank vehicles are unloaded into aboveground storage that may or may not be adequately grounded (e. g., airplane fueling), the truck is first grounded, then bonded to the receiving storage and then the nozzle is bonded before refueling begins. There are special precautions taken with the refueling of airplanes from tank vehicles since both have been subject to static accumulation due to the air and tire movement described above. For example, the US Air Force has discontinued the use of alligator clamps and now uses jack assemblies.

However, unloading into underground fiberglass, interior lined and steel storage tanks does not present a static ignition hazard, provided that the delivery hose nozzle is in metallic contact with the tank fill pipe, or tight connections are used. Experience indicates that the outside of a buried fiberglass, interior lined or steel tanks is in contact with a conducting medium (i.e., ground), and accumulated static charges are dissipated.

B. Tank Cars, Marine Vessels

Generally, tank cars are sufficiently well grounded through the rails, and bonding of the tank car is not necessary for protection against static generation. However, there is the possibility of stray currents (see Part II, Lightning and Stray Currents), and the loading lines should be bonded with the rails to assure a permanent bond.

Marine vessel loading and unloading does not require bonding cables between the vessel and the shore. This is unique since the hull of the vessel is inherently grounded by virtue of its contact with water. Thus, accumulation of static charges on the hull is prevented.

Instead, an effort is made to electrically separate the loading and unloading lines from the shore piping by inserting an insulating flange between the vessel piping manifold and the shore piping manifold.

C. Aboveground Steel and Fiberglass Storage Tanks

There is product movement during filling that can develop a static charge between the liquid surface and tank shell, or metallic fittings, in a non-metallic tank (e. g., manhole). To minimize the risk: avoid splash filling, limit the velocity of the incoming stream, avoid ungrounded objects in the tank (e. g., gauge floats), don't introduce entrained air with product flow, and allow a minimum relaxation time of 30 minutes for the charge to bleed off before opening.

Internal floating-roof tanks require some form of bonding between the floating roof and the tank roof. Open floating-roof tanks require bonding shunts between the floating roof and the tank wall. While these shunts are required for lightning protection (See Part II, Lightning and Stray Currents), they also provide protection from electrostatic charges caused by the product's movement.
Note: The addition of grounding systems (e. g., grounding rods) will not reduce the hazard associated with electrostatic charges in the liquid.

D. Portable Drums and Cans

Drums and container filling-line operations on conducting conveyors should not require additional protection against static accumulation. However, relaxation time should be provided downstream of any micron-type filters.

Single metal containers should be filled with metal spouts that are held in contact with the container or a funnel throughout the filling operation to prevent static accumulation and discharge. However, when transferring into or out of open top (i.e., not spout equipped) containers, the filling stream is broken and splashing occurs. In these operations (e. g., filling an open pail from a drum), a bonding wire should be used to connect the two containers.

Plastic containers are not conductive to a metal filling spout or funnel and can accumulate a static charge on the liquid surface. This may cause a discharge to the spout as the liquid level rises. When large plastic containers are filled, a grounding rod (i. e., connected to a bonding wire) should be inserted to the bottom of the container before filling. A recent survey documented 27 gasoline fires involving the filling of both metal and plastic containers on a plastic truck bed or carpeted car trunk. However, small plastic containers (e. g., one gallon) are less of a problem if the filling velocity is slow and the container is placed on the ground surface.

E. Vehicle Fueling

Experience indicates that fuel dispensing does not require bonding for fueling from a service station type dispenser at rates below 25 gpm. However, faster fueling of large equipment (e. g., aircraft) requires bonding the hose nozzle to the receiving equipment with a bond wire and clip.

F. Piping Systems

Small Diameter Piping: Static electricity accumulation is most likely to be a problem in pipes conveying non-polar fluids at high velocities. Typical small diameter underground fiberglass and steel piping (e. g., 2 to 6 inches) for motor fuel refueling is not considered a discharge hazard. However, large diameter piping that is located in general industrial service, where electrical charge build-up is possible (e. g., aviation installations) is a potential hazard.

Large Diameter Piping: Jet fuel movement in large pipelines has been the subject of U.S. Air Force studies on static electricity. Both buried steel and fiberglass piping were found to build up static electricity at about the same rate with fluid flows up to 15 ft/sec. The study also found that the charge was conducted along the layer of fluid next to the inside pipe wall and was drained off non-metallic piping when the fluid came in contact with metal valves or fittings.

Although test data is limited, 10-to12 ft/sec is considered to be the maximum velocity for non-metallic piping handling jet fuel, and metal valves or fittings should be properly grounded.

Another method of discharging static electricity from non-metallic piping is by co-mingling conductive fibers, such as carbon fibers, with the fiberglass and creating a conductive “grid” within the pipe wall. The composite is grounded by attaching a grounding saddle at approximately 60-foot intervals.

In the case of double-wall pipe, where the build-up of static electricity is possible, the primary pipe must be conductive and connected to ground or be made conductive by wrapping a copper wire around the primary pipe in a helix and grounding it by passing it through a threaded outlet saddle on the secondary pipe.

Non-metallic fiberglass pipe and fittings are available with conductive fibers entrained in the resin and meets MIL-P-29206A for jet fuels and petroleum liquids.

G. Filters and Relaxation Chambers

When a fluid is pumped through a pipe, the magnitude of the electrostatic charge generated will increase as the velocity increases. When this liquid is transferred into a smaller pipe, the liquid velocity will increase as will the static charge. When a filter is placed in the pipe, the static charge generation increases by a factor of 10 to 100. However, there is no danger from this excessive charge as long as the liquid is kept in the pipe (i.e., not discharged). Thus, before the liquid is discharged at least 30 seconds relaxation time should be provided in the piping system by means of a relaxation chamber between the filter and the point of discharge.

VIII. Special Situations

A. Switch Loading

Potential ignition conditions can exist when low-pressure product is loaded into a vessel that contains a flammable vapor from previous use at or above the lower flammable limit. The most common example is the loading of diesel fuel into a tank transport that previously contained gasoline. However, similar conditions can develop when product lines are flushed, manifold valves leak, and during vacuum truck operations. Static generation will be reduced by filling at the lowest possible rate until agitation is minimized or blanketing the liquid surface with an inert gas.

B. Sampling, Gauging, and High-Level Devices

Both conductive probes and insulating conductive floats can cause sparking at surface potentials much lower than those required for sparking from the free oil surface to the vessel or the vessel's internal supports. It has been found that there is a slower than normal decay of field strength (i. e., due to relaxation) in large storage or ship's tanks thus, 30 minutes delay should be observed before hand gauging or sampling. In smaller vessels, (e. g., tank trucks, tank cars), a one-minute delay time should be sufficient to allow for dissipation of the static charge.

C. Purging and Cleaning Tanks and Vessels

Purging involves removing a fuel vapor from an enclosed space and completely replacing it with air or inert gas. The purging operation can involve static electricity generation if steam jets, or CO2 jets are discharged into a flammable vapor-air mixture. Both steam and CO2 can generate static charges on the nozzle and should be avoided.

Vacuum trucks are often used to remove hydrocarbon liquids from vessels that are being cleaned. Ignitions may occur unless suction hoses and conductive pipe wands have electrical continuity.

Refilling of empty vessels when returned to service, should begin at the lowest flow rate to avoid the incoming stream from breaking the liquid surface. And, in the case of floating roofs, the flow should be reduced until the roof is floating off its support legs.

Part 2. Lightning and Stray Currents

I. Lightning Protection

Introduction: Lightning is nature's greatest manifestation of static electricity. Falling raindrops develop a static charge by breaking and separating and bringing one charge to earth and leaving a separate charge in the cloud. Thus, electrical storms involve the relatively slow movement of these heavily charged clouds, which set up an electrostatic field over a large area of the earth's surface below the cloud. The charge on the earth's surface includes tanks, equipment and other objects. As the cloud passes through the atmosphere, the opposite ground surface charge follows the cloud. In this scenario, lightning (i.e., electrostatic discharges) may impact facilities or equipment located on the earth's surface in the following manner:

a. *Direct-stroke Lightning:* At some point, when the gap between the cloud and an object on the earth's surface narrows, there is a direct lightning stroke. When this happens, a heavy ground current flows toward the impact point where facilities or equipment are in the path of a high lightning-caused current. Direct stroke lightning generates high temperatures that can severely damage objects in its path and ignite flammable materials.
b. *Indirect Lightning Currents:* The abrupt change in the electrical field caused by direct-stroke lightning neutralizes the static charge almost instantaneously and

collapses the field. These abrupt changes can induce secondary sparking at equipment that is relatively remote from the direct stroke.

c. *Cloud-to-Cloud Lightning:* The static charge developed by the breaking and separating of raindrops brings one charge to earth and leaves a separate charge in the cloud. As a result, adjacent clouds and the ground charge beneath each cloud may have opposite charges. When the gap between the charged clouds narrows or accumulates a heavy charge, lightning will occur between these clouds. While this neutralizes the charged clouds, the earth bound charges will also neutralize by way of a passage of current through the conductor with the lowest path of resistance (e. g., ground, and pipeline). These abrupt changes can induced charge-causing sparks, and usually occur when an insulated metallic body is present.

Nature has a way of preventing most lightning-caused electrical discharge damage, since cloud formation is often accompanied by high humidity. While high humidity does not prevent the generation of static electricity, it does help bond earth surface bodies to the ground and dissipates the electrical charge.

However, the accepted method of artificial protection against damage from direct-stroke or indirect stroke lightning is to dissipate the charge with a minimum of damage. Metallic structures that are in direct contact with the ground or bonded to the ground (e. g., underground piping) are sufficiently well grounded to provide safe dissipation of lightning strokes. However, artificial grounding (e. g., ground rods) does not provide adequate dissipation and damage may result. Non-metallic structures may be protected from direct-stroke lightning by means of properly designed lightning rods, conducting masts or overhead wires.

The accepted method of protection against damage from induced ground currents is to bond structures and equipment to each other and provide a low resistance path for the ground current.

A. Aboveground Tank Protection

Ground mounted metallic fixed roof and horizontal tanks are bonded to the ground and will safely dissipate direct-stroke lightning. However, these tanks are known to ignite when flammable vapors are venting through roof openings (e. g., gauge hatches) or vents not adequately equipped with back-flash devices such as pressure-vacuum vent valves. Non-metallic tanks must be protected against direct-stroke lightning by lightning rods or other means.

Open floating-roof tank “rim fires” occur when there is a direct-stroke lightning or when an induced charge is released by clouds discharging to the ground in the tank vicinity. Most of these fires occur above the seal and are extinguished with hand foam or dry-chemical extinguishers. The most common method of protection is to install metallic straps (shunts) on the circumference of the roof, between the floating roof and the metallic shoe that slides on the inside of the shell. These shunts will permit the charge to drain off without igniting the vapor in the seal area.

Internal floating-roof tanks are typically covered with conductive roofs that will act as “lightning rods.” However, the floating roof still requires bonding to the shell for protection against electrostatic charges due to product flow.

II. Stray Current Protection

Introduction: The term *stray current* applies to any electrical current flowing in paths other than those deliberately provided for it. Such paths include the earth, pipelines, and other metallic structures in contact with the earth.

Stray currents can accidentally result from faults in electrical power circuits, cathodic protection systems or galvanic currents resulting from the corrosion of buried metallic objects. While stray current voltages are typically not high enough to spark across an air gap, intermittent charges can result in a spark that would ignite a flammable mixture, if present.

A. Pipelines: Where stray currents are known or suspected in a pipeline, arcing at points of separation (e. g., valves, and spools) is reduced by connecting a bond wire of reasonably low electrical resistance.

B. Spur Tracks: Tank cars loading or unloading spots on spur tracks are typically served by a pipeline located alongside the rails. Stray currents may flow in the pipelines or in the rails. Thus, the pipeline and rail should be permanently bonded with low electrical resistance material.

C. Wharf Lines: The resistance of the vessel's hull to ground (water) is very low and the connecting and disconnecting of wharf piping may produce sparks. Insulating flanges in the pipe manifold proved the best assurance against sparking at the point of connection and disconnection of the hose.

D. Cathodic Protection Systems: Generally, an engineering study is required to locate and size bonding when cathodic protection systems are employed to protect a facility against corrosion. For example, the option of de-energizing an impressed current system does not immediately remove the potential and render it safe, since the polarized metal structure will persist for a period of time.

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References

Following is a list of relevant published references and videos for those wishing to explore the subject of static electricity further:

1. *Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents*, American Petroleum Institute (API) RP
2. *Precautions Against Electrostatic Ignition During Loading of Tank Truck Motor Vehicles*, API Publication 1003
3. *Safe Operation of Vacuum Trucks in Petroleum Service*, API Publication 2219
4. *Safe Entry and Cleaning of Petroleum Tanks*, API Publication 2015
5. *Cleaning of Mobile Tanks in Flammable or Combustible Liquid Service*, API Publication 2013
6. *Ignition Hazards Involved in Abrasive Blasting of Atmospheric Hydrocarbon Tanks in Service*, API Publication 2027
7. *Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter*, ASTM D 4308
8. *Static Electricity*, National Fire Protection Association, (NFPA) NFPA RP 77
9. *Lightning Protection Code*, NFPA 78
10. International Safety Guide for Oil Tankers and Terminals, OCIMF
11. *Aviation Ground Operation*, Safety Handbook, National Safety Council
12. *Electrostatic Charging Test for Aviation Fuel Filters*, Coordinating Research Council, Inc.
13. *Survey of Portable Container Fires 1990 through 1995*, Petroleum Equipment Institute
14. *Aboveground Storage Tank Guide*, Thompson Publishing, June 1996
15. *Bondstrand Series 7000 Anti-Static Fiberglass Pipe and Fittings*, Ameron, Fiberglass Pipe Group
16. *Engineering and Design Guide*, Smith Fiberglass Products Inc.

17. *Flammability Characteristics of Combustible Gases and Vapors*, U.S. Bureau of Mines, Bulletin 627
18. Video – *Minimizing Static Electricity*, U.S. Bureau of Mines, A Kennedy Production
19. Video – *Great Balls of Fire*, U.S. Air Force
20. Video – *Minimizing Static Electric Hazards*, Gulf Publishing Company, Houston, TX