U.S. Chemical Safety and Hazard Investigation Board

Barton Solvents

Static Spark Ignites Explosion Inside Flammable Liquid Storage Tank

No. 2007-06-I-KS

ISSUES

- Nonconductive flammable liquids can accumulate static electricity during transfer and storage.
- Static sparks can readily ignite flammable vapor-air mixtures inside storage tanks.
- Material Safety Data Sheets (MSDSs) often do not adequately communicate hazard data and precautions.

Who's at Risk…

Companies that transfer (pump) bulk flammable liquids into or from storage tanks.

1. INTRODUCTION

On July 17, 2007, at about 9 a.m., an explosion and fire occurred at the Barton Solvents Wichita facility in Valley Center, Kansas. Eleven residents and one firefighter received medical treatment. The incident triggered an evacuation of Valley Center (approximately 6,000 residents); destroyed the tank farm; and significantly interrupted Barton's business. An investigation by the U.S. Chemical Safety and Hazard Investigation Board (CSB) has concluded that the initial explosion occurred inside a vertical above-ground storage tank that was being filled with Varnish Makers' and Painters' (VM&P) naphtha. VM&P naphtha is a National Fire Protection Association (NFPA) Class IB flammable liquid[1] that can produce ignitable vapor-air mixtures inside tanks and, because of its low electrical conductivity, can accumulate dangerous levels of static electricity.[2]

The CSB is publishing this Case Study to help companies understand the hazards associated with static-accumulating flammable liquids that can form ignitable vapor-air mixtures inside storage tanks. In addition, the CSB wants to urge companies to take extra precautions to prevent explosions and fires like the one at Barton. This Case Study also examines industry Material Safety Data Sheet (MSDS) hazard communication practices and makes recommendations to ensure that MSDSs identify these hazards and outline appropriate precautions.

[1] Liquids most likely to form ignitable vapor-air mixtures during tank filling at ambient operating temperatures are normally those designated as Class IB or Class IC in NFPA 30 (flammability hazard rating of "3" in NFPA 704). In the American Petroleum Institute (API) classification system these liquids usually fall into the "Intermediate Vapor Pressure Products" category. A notable exception is motor gasoline, an NFPA Class IB liquid that is designated as a "High Vapor Pressure Product" in the API system, implying that (except at very low operating temperatures) the vapor-air mixture formed during tank filling rapidly becomes too rich to be ignitable. (See NFPA 30, Section 4.3 "Classification of Liquids" and NFPA 704 Chapter 6 for a detailed discussion of NFPA's classification and flammability hazard rating systems. See API 2003 (2008 edition), Section 3 "Definitions" for an explanation of "High," "Intermediate," and "Low" vapor pressure product classes.

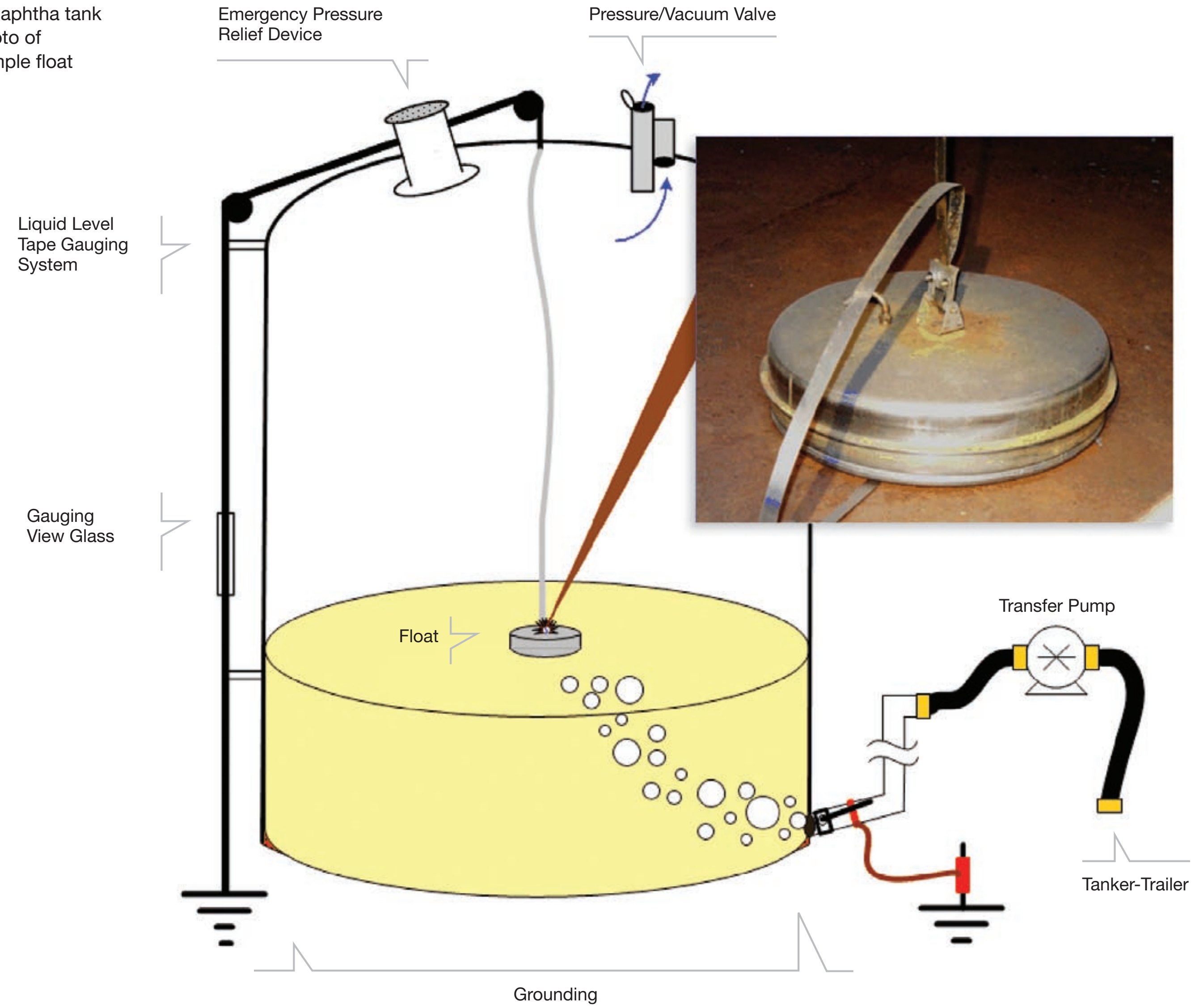
[2] On October 29, 2007, fire destroyed a large portion of a Barton facility in Des Moines, Iowa. Flammable liquids and static electricity were also involved in that incident. Because of the incident-specific findings associated with the Wichita incident investigation, this Case Study focuses solely on the Wichita incident.

2. INCIDENT DESCRIPTION

The initial explosion occurred soon after the tank farm supervisor started the transfer of the final compartment of a tanker-trailer containing VM&P naphtha into a 15,000 gallon above-ground storage tank (Figure 1).

FIGURE 1

VM&P naphtha tank and photo of an example float



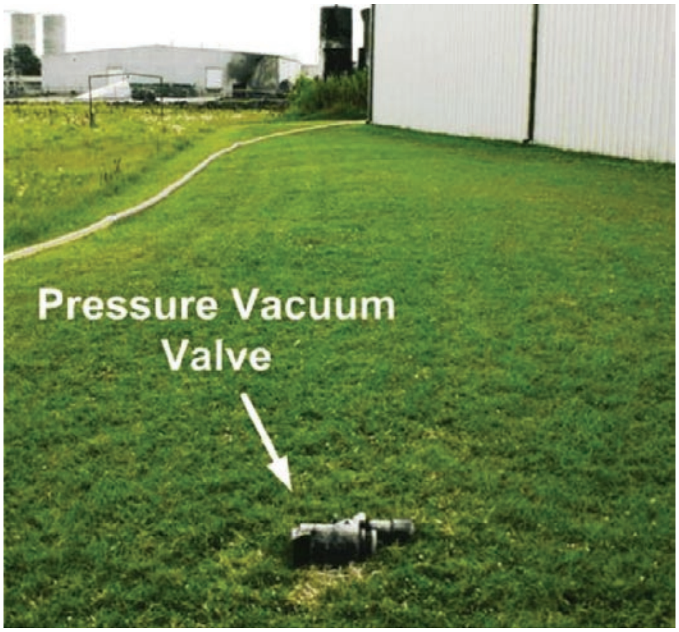
The explosion sent the VM&P tank rocketing into the air, trailing a cloud of smoke and fire from the burning liquid; it landed approximately 130 feet away. Witnesses heard the explosion and saw the fireball from several miles away. Within moments, two more tanks ruptured and released their contents into the rapidly escalating fire that was concentrated inside the earthen spill containment area surrounding the tank farm.[3] As the fire burned, the contents of other tanks over-pressurized or ignited, launching steel tank tops (10-12 feet in diameter); vent valves; pipes; and steel parts off-site and into the adjoining community. A tank top struck a mobile home in the community (approximately 300 feet away) and a pressure/vacuum valve hit a neighboring business nearly 400 feet away (Figures 2 and 3).

FIGURE 2

Tank top projectile struck a mobile home

FIGURE 3

Pressure vacuum valve projectile struck neighboring business



[3] Approximately 20,000 gallons of flammable liquid were released into the spill containment. The tank farm included 43 above-ground storage tanks with capacities ranging from 3,000 to 20,000 gallons. Tank heights ranged from approximately 15 to 40 feet.

3. FLAMMABLE LIQUIDS AND STATIC ELECTRICITY

Fire occurs when there is an ignitable vapor-air mixture and a source of ignition, such as a static electric spark. At normal handling temperatures, flammable storage tanks, like those containing gasoline, may contain vapor-air mixtures that typically cannot be ignited by a static electric spark because the vapor-air mixture is too rich (i.e., contains too much fuel and not enough oxygen) to burn. VM&P naphthas, however, and other flammable liquids (e.g., many NFPA Class IB Flammables), may form ignitable vapor-air mixtures inside tanks at normal handling temperatures.

Static electricity is generated as liquid flows through pipes, valves, and filters while being transferred.[4] It can also be produced by entrained water or air, splashing or agitation, and when sediment in the bottom of the tank becomes suspended (Britton, 1999).

Because nonconductive liquids, such as VM&P naphtha and other flammable liquids, dissipate (or "relax") static electricity slowly, they pose a risk of dangerous static electric accumulation that can produce sparks inside tanks.[5]

Common Static-Accumulating Flammable Liquids That May Form Ignitable Vapor-Air Mixtures

- VM&P naphtha
- Cyclohexane
- n-Heptane
- Benzene
- Toluene
- n-Hexane
- Xylene
- Ethyl benzene
- Styrene

4. KEY FINDINGS

The CSB determined that several factors likely combined to produce the initial explosion:

- The tank contained an ignitable vapor-air mixture in its head space.
- Stop-start filling, air in the transfer piping, and sediment and water (likely present in the tank) caused a rapid static charge accumulation inside the VM&P naphtha tank.
- The tank had a liquid level gauging system float with a loose linkage that likely separated and created a spark during filling.
- The MSDS for the VM&P naphtha involved in this incident did not adequately communicate the explosive hazard.

Normal Bonding and Grounding May Not Be Enough!

Companies that handle, transfer, and store flammable liquids should contact manufacturers to determine if these liquids can accumulate dangerous levels of static electricity, and if they can form explosive vapor-air mixtures inside storage tanks. If so, extra precautions—beyond normal bonding and grounding—may be necessary.

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[4] The rate of static charge generation during flow through pipe increases roughly with the square of the flow velocity. A liquid whose conductivity is less than 100 pico siemens per meter (pS/m) is generally considered nonconductive (Britton, 1999). The VM&P naphtha involved in the Barton incident had a conductivity of 3 pS/m. Some common nonconductive liquids are listed in NFPA 77 (Annex B – Table B.2). See the Resources Section at the end of this Case Study for web access instructions.

[5] The length of the transfer piping from the pump to the storage tank was approximately 215 feet (66 meters); the piping was 2.5 inch NPS Schedule 40, (6.3 cm inside diameter); and the pump flow velocity was 4.6 meters per second (15 feet per second). A 425 micron (0.017 inch) mesh strainer was located at the pump outlet.

4.1. FLAMMABILITY OF VM&P NAPHTHA

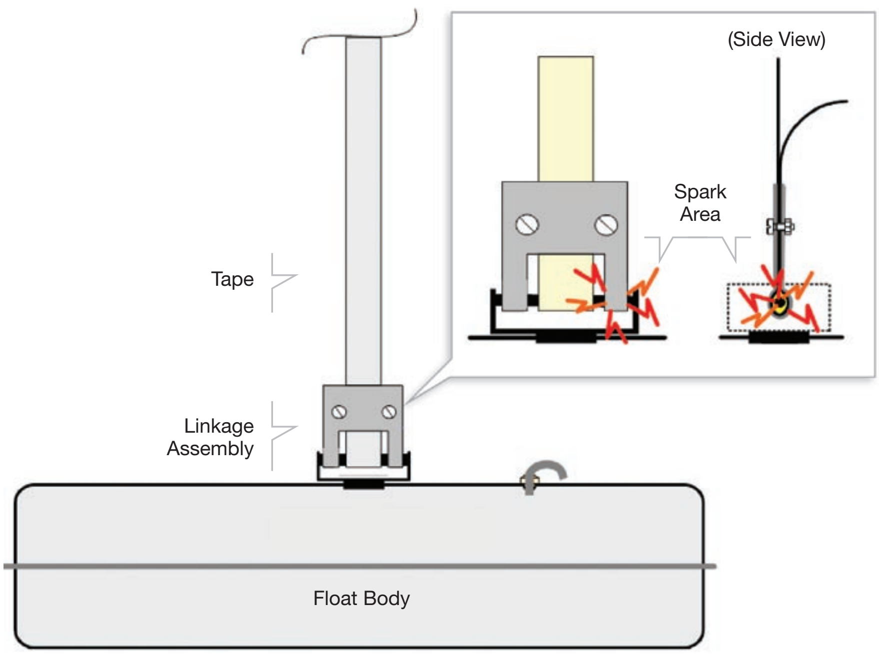
The CSB tested the VM&P naphtha involved in the Barton explosion to determine if an ignitable vapor-air mixture could have been present inside the tank at the time of the explosion.[6] The results revealed that, at approximately 77˚F (25˚C) (the handling temperature of the VM&P naphtha at the time of the incident), the tank head space likely contained a readily ignitable vapor-air mixture. The energy from a static spark would have been adequate to ignite this vapor-air mixture.[7]

4.2. TANK LEVEL FLOAT DESIGN

The design of the tank liquid level gauging system float used by Barton incorporates a loose linkage at the float/tape junction that can separate slightly, interrupting grounding (see Section 4.3) and creating the potential for a spark (Figure 4).[8] The CSB concluded that turbulence and bubbling during the stop-start transfer pumping, in addition to creating rapid static charge accumulation, also likely created slack in the gauge tape connected to the float, causing the linkage to separate and spark.[9]

FIGURE 4

Float linkage and area where the spark likely occurred



[6] Its flashpoint was 58˚F (14˚C); its vapor pressure was approximately 0.7 kPa (5 mmHg) at 68˚F (20˚C) using an Isoteniscope; and its flammable range was approximately 0.9-6.7% in air. The Reid VP of the VM&P naphtha was 3.1 psia (21.4 kPa) at 100˚F (38˚C).

[7] The CSB estimates that the minimum ignition energy required for a spark to ignite the Barton VM&P naphtha was 0.22 mJ (plus/minus 0.02 mJ).

[8] Electrical testing of an exemplar tank level float indicated that a loose linkage could produce a spark with sufficient energy to ignite a flammable vapor-air mixture inside a tank.

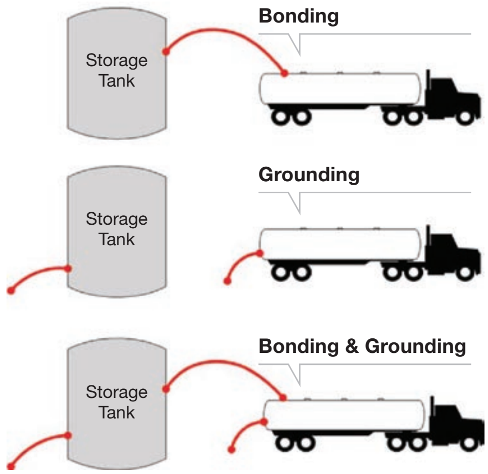
[9] While the CSB has concluded that the loose linkage level float was the most likely spark location, a spark from a "brush discharge" cannot be ruled out. Brush discharges encompass a variety of "non-spark" static discharges that occur between a charged liquid surface and a grounded conductive object, such as a dip pipe or other metal component acting as an electrode, or even the tank wall itself. Brush discharges can occur even when all equipment is properly bonded and grounded (Britton, 1999). See the Resources Section at the end of this Case Study for more information on brush discharge.

4.3. BONDING AND GROUNDING

Bonding is the process of electrically connecting conductive objects, like tanker-trailers, to transfer pumps to equalize their individual electrical potentials and prevent sparking (Figure 5).

FIGURE 5

Bonding and grounding



Grounding (earthing) means connecting a conductive object to the earth to dissipate electricity, like accumulated static, lightning strikes, and equipment faults, into the ground, away from employees/equipment and ignitable mixtures.

According to witnesses at Barton, the tanker-trailer, pump, piping, and storage tank were bonded and grounded at the time of the incident.[10] However, published safety guidance indicates that bonding and grounding measures applied to typical transfer and storage operations may not be enough if nonconductive flammable liquids are involved. Nonconductive liquids accumulate static electricity and dissipate (relax) it more slowly than conductive liquids, and therefore require additional precautions (see Section 5).

4.4. STATIC ACCUMULATION IN THE PUMPED LIQUID

Barton pumped the VM&P naphtha from three separate compartments in the tanker-trailer to the VM&P tank. Air pockets were introduced into the fill piping, and then transferred into the tank when the transfer hose was reconnected to the tanker-trailer after compartments were changed. Studies have found that static electricity accumulates rapidly during pump startup when nonconductive liquids are transferred to storage tanks (Walmsley, 1996). In this case, the static electricity accumulation was likely exacerbated by the air pockets (bubbling) and the likely presence of suspended sediment and water in the tank.[11] In addition, the VM&P tank was approximately 30 percent filled at the time of the explosion, which would have produced a liquid surface potential (voltage) close to the maximum expected during filling.

[10] The transfer hose was severely damaged during the fire, however, which prevented investigators from determining if bonding/grounding was effective.

[11] Barton indicated that it had no records of the VM&P tank ever being cleaned, and the tank had no manway or access opening to facilitate cleaning. Employees stated that they scooped sediment from the bottoms of similar tanks to prepare them for inspection.

4.5. MATERIAL SAFETY DATA SHEETS

According to the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (HCS),[12] employees both need and have the right to know the identities and hazards of the chemicals they are exposed to when working. The purpose of the HCS is to ensure that chemical manufacturers and importers evaluate the hazards and communicate them, along with appropriate precautionary measures, to employers and employees through a hazard communication program.[13] The primary method of communicating this information is via detailed technical bulletins called Material Safety Data Sheets (MSDSs).

The MSDSs supplied by the manufacturer of the Barton VM&P naphtha indicated that the material may accumulate a static electrical charge that could discharge and ignite accumulated vapors. It did not, however, provide critical physical and chemical property data and warnings that the material may form an ignitable vapor-air mixture inside storage tanks. Nor did it list any precautionary measures, beyond normal bonding and grounding practices, or reference relevant consensus guidance that Barton could have used to help prevent this explosion.

To prevent explosions with flammable liquids like VM&P naphtha, MSDSs should communicate

- warnings that the material is a static accumulator and can form an ignitable vapor-air mixture inside storage tanks;
- that bonding and grounding may not be enough;
- specific examples of additional precautions (see Section 5) and references to the published guidance targeted at preventing static electric discharge; and
- conductivity testing data,[14] so that companies know the degree to which the material will accumulate static and can compare it to the published guidance. Information about the published guidance is included in the Information Resources section at the end of this report.

Material Safety Data Sheets (MSDSs)

MSDSs do not typically communicate critical physical and chemical properties, and specific precautions or reference guidance for flammable liquids that may pose a static ignition hazard. Companies should contact the manufacturer (or an expert familiar with the relevant consensus guidance) for this information. Manufacturers should in turn update their MSDSs to provide this critical safety information.

[12] 29 CFR 1910.1200.

[13] 29 CFR 1910.1200(a)(1) and (2).

[14] The units routinely used to report conductivity are pico Siemens per meter (pS/m).

4.5.1. INDUSTRY MSDSs REVIEW

The CSB reviewed 62 MSDSs of some of the most widely used nonconductive flammable liquids to determine if they provided the warnings, precautionary measures and references, and conductivity testing data discussed above.

- **Static Accumulator and Storage Tank Ignitable Vapor-Air Mixture Potential:** Of the MSDSs reviewed, 39 (67 percent) contained a warning about the potential for the material to accumulate static electricity. Nearly all (97 percent) included a warning about ignitable flammable vapors. However, only one specifically warned of the potential for the material to form an ignitable vapor-air mixture inside a storage tank.
- **Specific Precautions and References to Prevent Explosions:** Of the MSDSs reviewed, 52 (84 percent) advised companies to properly bond and ground equipment, but only seven (all prepared by the same manufacturer) indicated that bonding and grounding alone may not be enough to prevent a static discharge. Each of the seven also referenced NFPA 77 and API 2003,[15] and 11 others referenced NFPA 77 and/or API 2003, but did not specifically warn that bonding and grounding may not be enough. Only eight of the 62 provided one or more specific precautionary measures such as adding nonflammable (inert) gases to tank head spaces, adding an anti-static agent, or reducing the pump flow velocity during transfer.
- **Conductivity Testing Data:** Only three MSDSs (all prepared by the same manufacturer) included conductivity testing data.

4.5.2. REGULATORY AND CONSENSUS GUIDANCE FOR PREPARING MSDSs

The three chemical hazard classification systems discussed in this section contain guidance to assist manufacturers who prepare MSDSs. OSHA establishes the regulatory requirements governing the content of an MSDS.

- **Occupational Safety and Health Administration:** OSHA describes the HCS as largely a performance-oriented standard that gives employers the flexibility to adapt the rule to the needs of the workplace, instead of having to follow specific, rigid requirements. Consequently, the HCS generally identifies categories of information to be included in the MSDS, including physical and chemical characteristics, physical hazards, and applicable precautions and/or control measures for handling materials safely. However, neither the standard nor its compliance directive[16] identifies the specific physical and chemical data, hazard warnings or precautions necessary to address some chemical hazards. The HCS places the responsibility on the preparer to identify the specific hazards within these broad categories.

  The OSHA advisory document, "Guidance for Hazard Determination For Compliance with the OSHA Hazard Communication Standard (29 CFR 1910.1200)," is intended to help MSDS preparers identify and communicate chemical hazards. While the document lists certain data and physical hazards recommended for inclusion in labels and MSDSs, it does not address relevant data and hazards associated with static-accumulating flammable liquids.

[15] NFPA 77 and API 2003 are consensus standards that provide static electric safety guidance.

[16] CPL 02-02-038 – CPL 2-2.38D, "Inspection Procedures for the Hazard Communication Standard."

- **Globally Harmonized System of Classification and Labeling of Chemicals (GHS):** The GHS, first adopted by the Sub-Committee on the Globally Harmonized System of Classification and Labeling of Chemicals (SCEGHS) in December 2002, is an initiative to establish international consensus on criteria for classifying chemical hazards for international distribution, and to create consistent requirements for MSDSs. The GHS has been revised twice: once in 2005, and again in 2007. According to the GHS Sub-Committee of Experts, the GHS is now ready for worldwide implementation.

  The GHS provides specific criteria for identifying and classifying flammable liquids, but it does not provide identification criteria or warning guidance for liquids that, in addition to being ignitable inside tanks at ambient temperatures, also accumulate static electricity that can ignite them. In addition, the GHS does not require a preparer to include conductivity testing data in an MSDS, data that are essential to identify a material as nonconductive.

  OSHA participates in the GHS criteria development process, and on September 12, 2006, published an Advance Notice of Proposed Rulemaking (71 FR 53617), indicating its intent to adopt the GHS guidance into the requirements of the HCS.

- **American National Standards Institute (ANSI) Z400.1-2004 "American National Standard for Hazardous Industrial Chemicals - Material Safety Data Sheets - Preparation":** ANSI Z400.1-2004 is a voluntary consensus standard, and is recognized by OSHA's HCS compliance directive as a consensus standard that provides valuable guidance to MSDS preparers.

  Because the OSHA HCS is performance-based, it provides minimal substantive guidance for MSDS preparers. ANSI Z400.1 was developed to provide such guidance; it identifies information that must be included in an MSDS to comply with OSHA's HCS, and includes additional guidance to help MSDS preparers comply with state and federal environmental and safety rules.

  ANSI Z400.1 gives the following example of a general warning about what practices to avoid or restrict: "To reduce the potential for static discharge, bond and ground containers when transferring material." However, the example does not warn that bonding and grounding may be insufficient to eliminate the potential for static discharge, particularly if the material is a nonconductive flammable liquid. The standard includes no additional precautions or relevant consensus guidance references, and no requirements for a preparer to include conductivity testing data in an MSDS.

5. ADDITIONAL PRECAUTIONS

Companies that handle, transfer, and store nonconductive flammable liquids, such as naphthas, toluene, benzene, and heptane, should take additional precautions to avoid an incident like the one at Barton.

Additional Precautions

- Request additional manufacturer guidance
- Add an inert gas to the tank head space
- Modify or replace loose linkage tank level floats
- Add an anti-static agent
- Reduce flow (pumping) velocity

5.1. REQUEST ADDITIONAL MANUFACTURER GUIDANCE

As discussed, MSDSs do not typically provide conductivity testing data or specific examples of additional precautions that should be observed, and do not typically reference the relevant consensus guidance pertaining to static electricity and storage tank vapor-air mixture hazards. Therefore, to determine if additional precautions to eliminate the potential for an explosion are necessary, companies that transfer flammable liquids should contact the manufacturers, or a qualified expert, to determine if the flammable liquid is

- nonconductive (a static accumulator); and
- capable of producing an ignitable vapor-air mixture inside a storage tank.

5.2. ADD A NONFLAMMABLE, NONREACTIVE (INERT) GAS TO TANK HEAD SPACES[17]

Using an inert gas such as nitrogen, if done correctly, is effective in reducing the potential for an ignitable incident (explosion) as it renders tank head spaces incapable of supporting ignition from a static spark.[18] However, because this practice can produce oxygen-deficient environments inside tanks, extreme caution should be exercised when opening tanks for routine inspections and maintenance.[19]

[17] See NFPA 69 "Standard on Explosion Prevention Systems" (2008) for guidance pertaining to proper inerting practices.

[18] Before using inert gases in tanks, companies should contact the liquid manufacturer to determine if the proposed gas is appropriate for the particular liquid.

[19] Employers who require employees to enter confined spaces—particularly those with oxygen-deficient or other hazardous atmospheres—must comply with the requirements of the OSHA "Permit Required Confined Space Program" (29 CFR 1910.146).

5.3. MODIFY OR REPLACE LOOSE LINKAGE TANK LEVEL FLOATS

Companies with tanks that may contain ignitable vapor-air mixtures and that are equipped with conductive loose linkage level floats should take one or more of the following measures:

- Use an appropriate gas to inert tank head spaces.
- Inspect and replace, as appropriate, floats with level measuring devices that will not promote sparks inside the tank.
- Modify floats so that they are properly bonded and grounded (see Figure 6).[20]
- Reduce the liquid flow (pumping) velocity.[21]
- Remove any slack in the tape connected to the float mechanism that could allow a spark gap to form.

5.4. ANTI-STATIC ADDITIVES

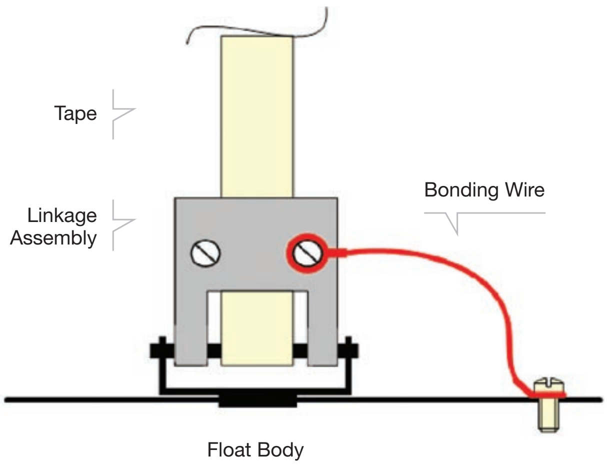
Anti-static (conductivity-enhancing) additives increase the conductivity of liquids, helping reduce static accumulation. Before relying solely on these additives, however, companies should contact the flammable liquid manufacturer to determine if such an additive is appropriate and effective for the particular liquid.

5.5. REDUCED FLOW (PUMPING) VELOCITY

Various guidance suggests that nonconductive flammable liquids capable of forming ignitable vapor-air mixtures inside tanks should be transferred at reduced flow (pumping) velocities to minimize the potential for a static ignition.[22]

FIGURE 6

Tank level float bonding wire



[20] This figure illustrates the modification recommended by the manufacturer of the floats used at Barton's Wichita facility. Companies with floats equipped with loose linkages should contact the manufacturer for modification recommendations.

[21] NFPA 77 (2007); API 2003 (2008); and Britton (1999) recommend a flow (pumping) velocity of 1 meter per second when the risk of static ignition is high. Until the spark potential inside the tank is eliminated, companies should use a pump flow velocity at (or near) 1 meter per second to transfer nonconductive flammable liquids.

[22] The guidance pertaining to reduced flow (pumping) velocities include API 2003 (2008), Sections 4.2.5.6 and 4.5.1; NFPA 77 (2007), Table 8.6 (footnote f); and Laurence Britton, "Avoiding Static Ignition Hazards in Chemical Operations", Chapters 2-1.6 and 5-4. While toluene and heptane are specifically identified in NFPA 77, Table 8.6 (footnote f), typical VM&P naphthas exhibit similar characteristics and should also be transferred at reduced flow rates. Recommended maximum flow (pumping) velocities provided in the various guidance differ. However, the most protective recommended flow (pumping) velocity is 1 meter per second.

6. RECOMMENDATIONS

6.1. OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

2007-06-I-KS-R1

Revise the "Guidance for Hazard Determination for compliance with the OSHA Hazard Communication Standard" to advise chemical manufacturers and importers that prepare MSDSs to

- Evaluate flammable liquids to determine their potential to accumulate static electricity and form ignitable vapor-air mixtures in storage tanks.
- Test the conductivity of the flammable liquid and include the testing results in the MSDS.

2007-06-I-KS-R2

Prior to the next revision, communicate to the Sub-Committee on the Globally Harmonized System of Classification and Labeling of Chemicals (SCEGHS) the need to amend the GHS to advise chemical manufacturers and importers that prepare MSDSs to

- Identify and include a warning for materials that are static accumulators and that may form ignitable vapor-air mixtures in storage tanks.
- Advise users that bonding and grounding may be insufficient to eliminate the hazard from static-accumulating flammable liquids, and provide examples of additional precautions and references to the relevant consensus guidance (e.g., NFPA 77, Recommended Practice on Static Electricity (2007), and API Recommended Practice 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents (2008)).
- Provide conductivity testing data for materials that are static accumulators and that may form ignitable vapor-air mixtures in storage tanks.

6.2. AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI) Z400.1 COMMITTEE

2007-06-I-KS-R3

Revise ANSI Z400.1 to advise chemical manufacturers and importers that prepare MSDSs to

- Identify and include a warning for materials that are static-accumulators and that may form ignitable vapor-air mixtures in storage tanks;
- Advise users that bonding and grounding may be insufficient to eliminate the hazard from static-accumulating flammable liquids, and provide examples of additional precautions and references to the relevant consensus guidance (e.g., NFPA 77, Recommended Practice on Static Electricity (2007), and API Recommended Practice 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents (2008)); and
- Provide conductivity testing data for materials that are static accumulators and that may form ignitable vapor-air mixtures in storage tanks.

6.3. INDUSTRY ASSOCIATIONS

AMERICAN CHEMISTRY COUNCIL
2007-06-I-KS-R4

AMERICAN PETROLEUM INSTITUTE
2007-06-I-KS-R5

NATIONAL ASSOCIATION OF CHEMICAL DISTRIBUTORS
2007-06-I-KS-R6

NATIONAL PAINT AND COATINGS ASSOCIATION
2007-06-I-KS-R7

NATIONAL PETROCHEMICAL AND REFINERS ASSOCIATION
2007-06-I-KS-R8

SOCIETY FOR CHEMICAL HAZARD COMMUNICATION
2007-06-I-KS-R9

Recommend to your membership companies that prepare MSDSs to update the MSDSs to

- Identify and include a warning for materials that are static accumulators and that may form ignitable vapor-air mixtures in storage tanks.
- Include a statement that bonding and grounding may be insufficient to eliminate the hazard from static-accumulating flammable liquids, and provide examples of additional precautions and references to the relevant consensus guidance (e.g., NFPA 77, Recommended Practice on Static Electricity (2007), and API Recommended Practice 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents (2008)).
- Include conductivity testing data for the materials that are static accumulators and that may form ignitable vapor-air mixtures in storage tanks.

7. INFORMATION RESOURCES

The following references include additional information on the safe use of static-accumulating flammable liquids:

1. American Petroleum Institute (API), "API Recommended Practice 2003: Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents," 7th ed., 2008.
2. Britton, L.G., and J.A. Smith, "Static Hazards of Drum Filling," *Plant/Operations Progress*, Vol. 7, No. 1 (1988) pg. 53-78.
3. Britton, L.G., "*Avoiding Static Ignition Hazards in Chemical Operations*," AIChE-CCPS Concept Book, 1999.
4. National Fire Protection Association (NFPA), "NFPA 30: Flammable and Combustible Liquid Code," 2008.
5. NFPA, "NFPA 69: Standard on Explosion Prevention Systems," 2008 ed.
6. NFPA, "NFPA 77: Recommended Practice on Static Electricity," 2007 ed. NFPA 77 can be viewed, free of charge, on the NFPA website (www.nfpa.org). Access directions: At the NFPA Homepage, go the "Codes and Standards" pull down tab, then click on "Code development process" and scroll down to "Online access."
7. Walmsley, H.L., "The Electrostatic Potentials Generated by Loading Multiple Batches of Product into a Road Tanker Compartment," *J. Electrostatics*, Vol. 38, 1996, pg.177-186.