ELECTROSTATIC DISCHARGE FIRES AT RETAIL FUEL TRANSFER FACILITIES REVISITED

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ABSTRACT

This research documents regulations and physical testing related to electrostatic charge separation and subsequent discharge that ignites flammable liquid fuels at retail fuel dispensing sites. Primary focus is issues with self-service distribution locations where patrons operate refueling equipment. The research reviews physics associated with electrostatic charge separation and conditions that lead to dangerous discharge; reviews some equipment involved in fuel transfer, and documents nationally applicable standards of care related to operations at self-service refueling sites. Conclusions include recommendations for increasing safety at these sites, the most prominent being mandating attendants assure patrons follow codes and standards while refueling. Suggestions for details to be documented when investigating fires at refueling sites are also included.

PROBLEM STATEMENT

Issues regarding fires at retail refueling sites were raised with warning issued Chevron U.S.A. regarding ignitions associated with dispensing gasoline into containers resting in pick-up truck beds equipped with plastic bedliners (Chevron, 2001) This bulletin warned, "The insulating effect of the plastic surface prevents the static generated by the gasoline flowing into the can from grounding. As static charge builds it can create a static spark between the gas can and the fuel nozzle." In a similar warning, the National Institute of Occupational Safety and Health (NISOH) issued recommendations to remove containers, especially plastic containers, to the ground before refueling. NIOSH further stated that problems exist when containers are filled in vehicles with carpet floor coverings. NISOH went further to recommend manufacturing plastic "bed liners that can be grounded to the metal truck bed, thereby dissipating potential electrostatic charge."

The authors became aware of the warnings while investigating fires involving similar situations involving fires with portable containers plus while transferring fuel into automobiles. These warnings were consistent with information promulgated by the Petroleum Equipment Institute (PEI). Review of PEI's information and discussions with their executive Robert Renkes, raised as many questions as were answered. Information provided tended to focus on issues related to patron activities and did not include discussion of equipment design and use. As of March 2010 PEI indicates 176 fire events have been reported to their website. This number seems statistically low, possibly reflecting that reporting is voluntary and sporadic. Particularly intriguing to the authors is seemingly contradicting reasons given by API, PEI and NISOH for ignition at portable containers and those involving vehicles. With portable containers, data tends to indicate discharge occurs because containers are not grounded, while static discharges generated from other actions ignite vapors escaping from vehicle refueling, with the preponderance of blame attributed to retail customers. This divergence warranted exploration to determine if commonalities are present in these situations.

The authors continue to investigate issues related to patron activities and equipment design. Much anecdotal information is present to indicate the problem has diminished but remains. Within the past year (July 2009 – July 2010) at least two incidents have been reported where electrostatic discharge is suspected in fires that resulted in death of patrons at retail fuel transfer locations, thus it is perceived that the problem continues. This paper is an update of a previous research reported by Pharr and Jonas in 2001.

Fires at common refueling locations raised numerous questions with the authors:

Why did these fires occur?
Why is this type of incident now reported more frequently?
Are plastic containers a safety hazard?
What, if any, correlation exists between fires in portable containers and those where automobiles are involved?
Are the actions of customers responsible for these fires?
What equipment issues contribute to these situations?
What can be done to prevent these situations?
What factors should investigators include to determine responsibility at these incidents?

LITERATURE REVIEW

A report issued by PEI, Fires at Refueling Sites That Appear To Be Static Related (March 2010) indicates that reports of 176 fire events during refueling were received between May 2000 and March 2010. Compiled for PEI by Robert N. Renkes, the report indicates the author is not an expert on static electricity, but indicates that many of the reports indicate "the refueler became charged prior to or during the refueling process through friction between clothing and the car seat to the extent that electrostatic discharges to the vehicle body, fuel cap or dispensing nozzle occurred." This report indicated 87 of the fires occurred when "the fueler re-entered the vehicle at some point during the refueling process, then touched the nozzle after leaving the vehicle" (Renkes, 2010). It should be noted that very few reports have been recorded to this database in recent years although many incidents have been promulgated in news sources.

PEI referred to the American Petroleum Institute (API) for additional information on the matter. API's *Gasoline Refueling Advisory and Safety Guidelines for Consumers* indicates that "static electricity related incidents at retail gasoline outlets are extremely unusual, but the potential for them to happen appears to be the highest during cool or cold and dry climate conditions." API indicates "Most important, they (patrons) should not get back into their vehicles during refueling – even when using the nozzle's hold open latch." The article indicates that staying outside will greatly reduce chances of static build-up and discharge. A recommendation is included for persons who must reenter the vehicle, touch the car or door away from the fill point prior to touching the nozzle. This information tends to indicate static generated by movement within the vehicle is primary culprit in static ignitions (API, 2001)

Research conducted by Fowler Associates indicates ignitions caused by static discharges pose problems within not only the United States, but European and Asian nations also. The ESD Journal published by Fowler reflects numerous accounts of ignitions during fueling operations.

The National Fire Protection Association's (NFPA) Standard *NFPA 77, Recommended Practice on Static Electricity, 2007 Edition* is cited often in this research. Section 1.1.6 of this standard specifically states, "This recommended practice does not apply to fueling of motor vehicles, marine craft or aircraft." However, section 1.2 of the document indicates the purpose of the recommended practice is "to assist the user in controlling the hazards associated with the generation, accumulation, and discharge of static electricity by providing the following: (1) Basic understanding of the nature of static electricity; (2) Guidelines for identifying and assessing the hazards of static electricity; (3) Techniques for controlling the hazards of static electricity; (4) Guidelines for controlling static electricity in selected industrial applications." Therefore we contend this document is applicable to retail fuel transfer situations (NFPA 77, 2007)

NFPA 30, *Flammable and Combustible Liquids Code* provides information related to static generation during fuel transfer and data regarding protecting facilities from static discharges. Much of the information contained in these documents indicates that static discharge ignitions at motor fueling dispensers do not occur frequently. These contentions seem outmoded; however, much information about static protection is included in sections addressing transfer of greater quantities of fuel. Section 6.5.4.1 specifies that "all tanks, piping and machinery used to transfer fuel be designed and operated to prevent electrostatic ignitions." These researchers hold that methods of static protection at motor fuel dispensers should be similar to that found at other fuel transfer locations (NFPA 30, 2008).

NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages* includes design and operational constraints for retail fuel dispensing facilities. Included are requirements for full-service, attended self-service and unattended self-service facilities. Full service is defined as a location where an employee of the retail fuel dispensing company dispenses fuel into the vehicle or other tank. Conversely constraints regarding self-service apply when the customer dispenses the fuel under the supervision of an attendant (attended) or without supervision (unattended) (NFPA 30A, 2008).

NFPA 407, Standard for Aircraft Fuel Servicing was examined to assess similarities and differences in fuel transfer requirements. NFPA 77 applies to ground refueling of aircraft using petroleum fuels. Data indicates the standard's "requirements are based upon sound engineering principles, test data, and field experience" (NFPA 407, 2007)

Electrostatic Ignitions of Fires and Explosions, by Thomas H. Pratt outlines basics of electrostatic charge separation and discharge. Concepts presented include breakdown currents (3,000 volts per millimeter). Pratt also indicates that liquids prone to accumulate static are more prone to electrostatic charge separation when air or gas is entrained. Many of the concepts covered in other references are also discussed within this text, including splash loading, fluid flow rate and charge separation in clothing (Pratt, 2000).

Chevron's web publications Handling Gasoline Safely, accessed in August of 2010 indicates that the flow of gasoline generates static electric charge which does not dissipate as readily when in a car or on a pickup truck bed, thus recommends placing containers on the ground before transferring gasoline into portable containers (Chevron, 2010)

ELECROSTATIC CHARGE SEPERATION AND DISCHRGE

To understand ignitions from static discharges, we must first understand static electricity development and discharge. Static electricity is a misleading term according to William J. Beaty, who says what is actually developed are high voltage – low amperage electrical charges (Beaty, 1999).

NFPA 77 defines Static Electricity as "An electric charge that is significant only for the effects of its electrical field component that manifests no significant magnetic field component" (NFPA 77, 3.3.17, 2007) In more common language, static electricity is electrical energy that has sufficient strength to arc once, but is unable to sustain continuous activity. "Static charge is formed whenever two surfaces are in relative motion, for example when a liquid flows through a pipeline…" (Keltz, 1995)

"Static electricity" results when electrical charges are separated from atoms, as they move and experience friction from adjacent surfaces. Separation of an electron from one atom causes the atom to have a positive charge, yet when that electron attaches to another atom, the second atom has a negative charge (NFPA 77, 2007). It should be noted that a surface having a deficiency of one electron in 100,000 atoms is considered strongly charged (Hammer, 1989) Typically the charge is diminished by recombining of electrons, often through moisture in the atmosphere or to earth through a grounding system. When the electrical charge builds without sufficient dissipation, any near contact with objects possessing differing charges poses the possibility of sudden discharge, commonly known as arcing. Voltages involved in static discharges are extremely high, while current (amps) remains relatively low (Beaty, 1999). One of the most common illustrations of static electricity is a person walking briskly across a carpet then coming in proximity of a grounding source. Electrical potential approximating 10,000 volts may develop and discharge may occur over a 1/8 inch space (Hammer, 1989), which is sufficient to ignite flammable vapors from most petroleum hydrocarbons (Pratt, 2000). Accumulated electrostatic charges are more probable in low ambient humidity atmospheres (less than 30%) than in atmospheres with higher humidity (greater than 65%) (NFPA 77, 7.4.2.1, 2007).

Electrostatic charge resides on surfaces rather than within molecules of the mass in which charge are generated. Capacitance is the ability of a mass to store electrical charge, in this case, disassociated electrons. Unit of measure for storage capacitance is Farads. More commonly, capacitance of common fuel and vehicle systems are expressed in micro or pico Farads. Electrostatic potential, expressed in Volts, is directly related to a body's capacitance and the charge (Coulombs) on a body. A Volt on a person or part is compared to the "pressure" within a body, or how robust the discharge can be. Higher voltages (pressure) tend to discharge with greater intensity than do lower voltages. Electrostatic charge is expressed in units known as Coulombs. (one Coulomb is -6.24×10^{18} electrons). A Coulomb is the amount of electrons required to generate one Volt of potential on a capacitance of one Farad.

With a given amount of liberated electrons stored on a body, as that body's capacitance increases, the voltage or potential voltage on the body drops. Conversely, as the capacitance decreases, voltage increases. This is expressed in the equation $C=Q/V$ where C is capacitance (in Farads), $Q = $ charge (in Coulombs), and V is voltage. The electrical capacitance of a mass, including liquids, is greatest when they are nearest to the earth. As the mass is raised above earth its capacitance decreases. As a body's capacitance decreases, the voltage increases for a given charge, thus when discharge occurs, one can anticipate more energy (higher temperatures) within the discharge area.

An analogy to demonstrate the relationship between capacitance and voltage is a balloon. Little resistance is encountered during this initial air infusion, i.e. simply inflating the vessel to it's normal capacity. Low pressure is encountered. Only a small amount of energy (pop) is released should rupture occur. As air pressure increases, the potential for violent discharge increases. Increased volume directly correlates to potential for discharge energy. If left alone, over a period of time, the balloon is likely to deflate, i.e. lose it's charge. With electrostatics this is expressed as "relaxation". As electrons are released to other bodies (i.e. the earth or atmosphere), charge decreases without damaging the vessel.

Should the balloon come in contact with a sharp object, violent discharge is likely when the balloon bursts from sudden release of pressure. Much the same occurs when a point to point electrostatic discharge occurs. A robust arc with accompanying heat energy occurs. Unlike a sharp point bursting a balloon, ESD (Electrostatic Discharge) has the greatest energy when allowed to discharge from more blunt objects like a human finger. When gasoline vessels are raised above earth during product transfer, not only are they electrically isolated from grounding, the mass has less capacitance. This voltage increases more rapidly than when transfer occurs at earth level. It should be noted that this issue has no correlation with grounding or bonding issues.

Electrostatic generation and discharge are not hazardous unless the discharge has sufficient energy to initiate combustion in the atmosphere in which the discharge occurred. The Minimum Ignition Energy (MIE) of gasoline is in the range of 0.25 millijoules (based on Toluene (0.24 mJ), Xylene (0.2 mJ, and N-Pentane (0.28 mJ) (NFPA 77, Table B-1, 2007) which approximates discharge of 2,000 Volts. In laboratory conditions the authors have consistently ignited gasoline vapors with 4,000 Volt electrostatic discharges and experienced similar results in field demonstrations with 10,000 Volt electrostatic discharges.

GASOLINE

Understanding the basics of combustion and flammable characteristics of gasoline are important to fully assess prevention measures for these fires. First one must understand that gasoline is a blend of petroleum hydrocarbons. Constituent hydrocarbons vary between brands, grades and seasonally. Variances result from difference in use, i.e. high octane gasoline, and for environmental concerns, i.e. winter versus summer blend. Additionally, blending of ethanol into commercially available gasoline alters charge separation characteristics, even in lower percentage (5-10%) blends. Ethanonl has conductivity of 135,000 pS/m and dielectric constant of 24.55 and is listed as conductive liquid, whereas unleaded gasoline is listed as nonconductive with conductivity less than 50 pS/m and no dielectric constant is listed (NFPA 77, Table B.2, 2007).

For ignition of any flammable vapors to occur, they must be mixed with air in proportions that are ignitable for that material. Flammable Range is the term used to describe the range of vapor to air mixture that will ignite. If the vapor concentration is below this range, the mixture is said to be lean. When the vapor concentration exceeds the range, the mixture is said to be rich. In either case, no ignition can occur.

Flash point it the temperature at which a material emits sufficient vapors to facilitate a fire to propagate through the vapors. Auto Ignition Temperature is the heat energy required to initiate a chemical reaction between the flammable vapors and oxygen in the air without exterior initiation such as a spark. Minimum Ignition Energy relates to the energy required to initiate combustion when the vapor to air mixture for a chemical is ideal. Vapor density indicates the relative weight of vapors in relation to air, any material with vapor density greater than 1 indicates the vapors will sink when mixed in air.

Gasoline in general has a flammable range of 1.4% to 7.6% vapors in air, flash point of -45^{o}f, and an Auto Ignition Temperature of 495^{o}C, vapor density of 3.0 to 4.0 (Marathon, 2009) and MIE between 0.21 and 0.25 millijoules (mJ) (NFPA 77). A volume of liquid gasoline will produce between 140 – 210 volumes of gasoline vapor depending on blend and ambient temperatures. When any constituent within the gasoline blend reaches its individual flammable concentration, ignition can result.

STATIC CHARGE SEPERATION IN FABRIC

Robert Renkes indicates the majority of static related ignitions at fuel dispensers result from patrons reentering their cars during refueling (API 2010), which as attributable to static accumulation on clothing discharging to the fueling system within an explosive atmosphere, Movement of fabric can generate electrical charges; however, in normally encountered atmospheric conditions where humidity is above 50%, these charges relax as quickly as they are generated. Studies indicate fabrics including nylon/wool, and nylon/cotton can produce electrical potential greater than 2,650 volts, enough to ignite sensitive materials" at 35% relative humidity (FM, 1997). When humidity was below 20% dangerous voltages were produced on the body, even with cotton. This information indicates that gasoline vapors can be ignited by discharge of this energy.

FUEL TRANSFER.

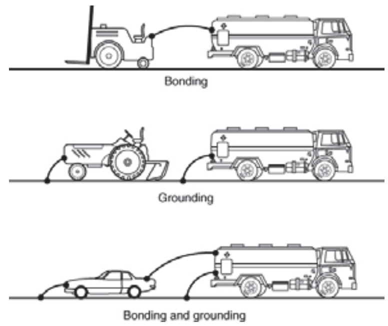
NFPA 77, 8.3.1 indicates separation of electrical charge (static generation) occurs when "liquids flow through pipes, hoses, and filters, when splashing occurs during transfer operations, or when liquids are stirred or agitated. The greater the area of interface between the liquid and surfaces and the higher the flow rate, the greater rate of charging." (NFPA 77, 2007). Nonconductive liquids generate static charge that does not quickly dispel, ranging from a few seconds to a few minutes to relax. Gasoline is listed as a non conductive, having varying conductivity <50 picosiemens per meter (pS/m), (NFPA 77, Table B-2, 2007) thus charges generated inside a pipe during transfer may be transferred to the receiving vessel (NFPA 77, 8.3.1, 2007) NFPA 407 Annex A indicates "The movement of the fuel through the pumps, piping, and filters of the transfer system causes the fuel to be charged electrostatically. If the charge on the fuel is sufficiently high when it arrives at the fuel tank, a static spark could occur that might ignite the fuel vapor" (NFPA 407, 2007). Generally acceptable maximum flow velocity to deter static accumulation is 3 feet (1 meter) per second.

Figure 20-4 of Occupational Safety Management and Engineering states: "When a fluid, such as diesel oil, flows through a pipe, liquid becomes charged because of its relatively low conductivity. This moving accumulation is known as a streaming current. It may enter the tank with the fuel, sometimes at extremely dangerous amounts. Once the liquid enters a tank, the charges may require hours to dissipate, the period depending on the relaxation time of the fluid and the material of which the tank is made. Generation of such accumulations by combustible fluids is especially hazardous since discharges can be ignition sources, which cause fires involving the very liquids producing the charges" (Hammer, 1989).

Splash loading is the process of transferring liquid from a hose into a tank wherein the liquid falls from a top connection or opening and/or splashes as it strikes the tank's base or the liquid surface. Turbulent movement of liquids from this method of transfer results in significant electrostatic charge separation when non-conductive or low conductivity liquids are involved. For this reason, NFPA 30 prohibits splash loading of flammable liquids in larger volume vessels. Liquid falling through air and droplet separation is an issue that often exasperates charge separation in splash loading operations.

Static Protection

The most common of these precautions is electrically connecting the dispensing and receiving vessels to assure equal electrical potential exists between them. The predominant term for assuring similar electrical charges are present in all components of a system is "grounding." Grounding, is arranging conductors so that all parts of a system are connected with earth. Bonding is similar to grounding in that components are electrically connected. Realistically, grounding is bonding with the earth. Bonding is the indicated preventive measure for assuring equal electrical potential in the dispensing and receiving vessels during liquid transfer (NFPA 77, 7.4.1, 2009).



NFPA 77, Figure 7.4.1

NFPA 77, *Recommended Practice on Static Electricity,* indicates that conductivity with 1,000,000 ohms (NFPA 77, 7.4.1.3, 2009) of resistance or less adequately bond materials to assure static charges are equal between vessels. When transferring gasoline into one's automobile at a properly constructed dispenser, bonding between the nozzle and vehicle is more probable when the metal filler tube remains in contact with the metal fuel fill attached to the vehicle. Filling portable containers offers less assurance of bonding, especially with plastic containers where bonding is impossible because the plastic is non-conductive. It should be noted that automobiles have varying assurance of bonding with the receiving vessel due to widespread use of non-conductive materials for filler tubes and composite materials for tanks.

When dispensing fuel into metal cans, the tendency for contact between the metal fuel nozzle and the metal can neck is fair. If contact is maintained, electrical conductivity necessary to assure electrical bonding results. Plastic fuel cans offer no such assurance of conductivity because plastic is not conductive, therefore no bonding results from even intentional direct contact with the earth. Fowler indicates reasoning for placing containers on or near the earth is not for grounding but rather to reduce the capacitance of fuels within the container. He indicates that capacitance, the ability of a body to retain electrical charge, increases with distance from earth. As fuel moves through conduits to the container, charges remain on the fuel and are stored within the container with voltages relating to their capacitance. "For example, 2 gallons of gasoline may have a potential of 6,000 volts a few feet above the ground but only 2,000 volts sitting on concrete." The potential increases with the distance between the container and earth.

An assumption that a static charge developed at the nozzle end of a fuel delivery system would transfer back, through piping and tanks, to the earth is generally accepted. NFPA 77 recommends that: "All parts of continuous all-metal piping should have resistance to ground that does not exceed 10 ohms." (NFPA 77, 7.4.1.3.1, 2009). Modern systems involve tanks constructed of non-conductive or protected materials, connected to plastic, non-conductive piping, are prone to static development. Within a closed system, lower threat of ignition is present. Pumps and metering devices may be grounded, but components such as flexible hoses, couplings, and nozzles must have conductivity within acceptable limits to offer reasonable assurance grounding is accomplished. Occupational Safety and Health Administration regulations prohibit employees from dispensing Class 1 flammable liquids into containers unless the nozzle and container are electrically interconnected. This essentially prohibits use of plastic fuel containers in the workplace. Husky Corporation, a manufacturer of petroleum dispensing equipment recommends testing conductivity from the nozzle to the dispenser, using a cumulative formula to determine acceptable resistance to ground. The cited example indicates 2.41 mega ohms resistance is acceptable for an assembly (Husky, 1999). It should be noted that this recommendation seems contradictory to NFPA recommendations and only addresses resistance from the nozzle to the dispenser, not nozzle to the earth.

Specialized voltage meters, commonly labeled meg-ohm meters, are needed to accurately determine conductivity within these systems. Common volt-ohm meters operate at approximately 1 volt, a current that is incapable of igniting gasoline vapors. Volt-ohm meters that utilize 500 volts provide a more realistic indication of continuity at voltages within which static discharges would not achieve Minimum Ignition Energy of gasoline.

CONDUCTIVITY

Directives dictate removing containers from plastic bed liners before refueling, but why? NIOSH indicates this "provides path to dissipate static charge to ground" (NIOSH, 1998) while Chevron indicated that the bedliner prevented static charges from reaching ground (Chevron, 2001). Contentions of these directives indicate that plastic bedliners inhibit dispersal of static charges developed during fuel transfer. Inferred information indicates that containers resting on metal truck beds or conductive bedliners, would possess electrical connectivity likely to discharge static charges. One could also infer that conductivity with the earth is established, however, this contention is not likely on rubber tired vehicles.

One may better understand placing a metal can on the ground to achieve grounding however widely popular plastic cans pose differing concerns because they are not conductive NFPA 77, 8.13.6.2, 2007). In reality, electrical connectivity to earth is not warranted regardless of the container, rather is largely a measure of soil conditions at the interface, most prominently the soil moisture content. Tests conducted at Fowler Associates revealed that conductivity of concrete varies widely with ambient humidity, moisture in the concrete provides conductivity thus when moisture evaporates from the upper regions only minuscule conductivity remains.

Gasoline is listed as a non-conductive material, therefore electrical connectivity between the liquid and container is minimal at best. Electrical flow through the container, especially a plastic container, is non-existent. Obviously, when automobiles are refueled, no intentional grounding is established unless it occurs through the nozzle and fueling system.

POLYMER BEDLINERS

Fowler Associates has made several attempts to cause electrostatic charge separation in fuel polymer and metal fuel cans sitting on polymer bedliners in the back of pick-up trucks. Prior to attempts verification that no electrostatic charge existed on the containers that were filled with gasoline was made then actions were taken to create charge separation. Actions include driving for more than 10 miles with the containers unsecured and moving across the bedliner, sliding containers across bedliners and rocking the vehicle from side to side to generate fluid movement within the containers. In no case did the electrostatic charge separation exceed Two Hundred volts (200v).

CONDUCTIVITY IN AUTOMOBILE FUEL DISPENSING SYSTEMS

In yesteryear, hydrocarbon fuels were generally stored in steel tanks constructed with a single metal wall separating fuel and soil. Conduit for transferring product from the storage tanks to dispensers was usually galvanized steel pipe. Both components provided intrinsic grounding for the entire system. Modern systems feature double wall tanks constructed of non-conductive materials connected to non-conductive, double wall pipe storing and transferring products. No intrinsic grounding is achieved with these systems that are designed to increase assurance of environmental safety.

Additionally it should be noted that no electrical interconnectivity is integral or added to systems to assure equal electrical potential between storage tanks and dispensing devices in typical United States installations. Some Asian and European entities require conductive piping, including those of polymer construction in retail fuel installations.

FUEL DISPENSER SYSTEM CONSTRUCTION

Pumps

Most systems utilized incorporate pumps submerged in the underground storage tank to transfer fuel through the non-conductive piping to the dispenser unit. Rarely are pumps located on the dispensing island as was common practice in earlier times. Because of their physical location, it is believed that pumps induce very little static into the system. Typical pumps are rated to deliver 40-80 gallons per minute to facilitate servicing several dispensers simultaneously. Liquid is pumped from the tank through a manifold and underground piping to the dispenser. Typical underground piping is generally non-conductive polymer piping that is double walled, meaning fuel is transferred within the inner orifice and the annulus is monitored for vapors that would indicate the inner conduit has developed a leak. Maximum fuel delivery rate for individual dispenser nozzles is 10 gallons per minute (GPM).

Dispenser

Unlike their predecessors that delivered fuel from side connections into hoses attached directly to nozzles, modern fuel dispensers transfer fuels to hoses mounted more than seven feet above grade level. Connected to non-conductive product lines are dispensers that incorporate metering devices with displays, either mechanical or electronic, to indicate volume delivered and total cost of the purchase. Metering devices are mounted inside cabinets that also house the displays and other dispenser components such as credit card readers.

Some dispensers use a mixing valve to blend low and high octane fuel to generate a mid range fuel for sale, while requiring only two storage tanks. These are identifiable as they have a single hose providing all grades of fuel delivered from the dispenser. Dispensers without this feature typically feature three hoses attached to the dispenser.

Piping from the metering mechanism to the dispensing hose is generally flanged connector copper piping, approximately $^{5}/_{8}$ inch in diameter. In the approximately six feet (6') from the dispenser to the hose connector, product must make three directional changes that approximate 90-degrees each.

Fuel Filter

Filters are placed in dispensing system piping approximately 25 feet prior to discharge from nozzle tips. Fuel flow through filter media experiences increased turbulence and contact, thus NFPA 77 suggests common industry practice is placing filters upstream to provide at least 30 seconds of time between filtration material and discharge to provide time for electrostatic charge relaxation (NFPA 77, 8.4.5.1.2, 2007). Fuel filters are rated in microns, usually between 10 and 30 microns, to indicate the filtering capacity, the smaller measurement is more efficient in removing contaminates, however also results in more charge separation. Additionally, filters with larger mesh (more microns) can reach levels of smaller opening when filled with contaminants.

Hose assembly

In most, if not all fuel delivery systems, $^{5}/_{8}$ or ¾-inch rubber lined hose is used. Approved hoses are equipped with conductive metal wrapping internal to hose construction, and generally constructed with a short hose connected between the dispenser and emergency disconnect (approximately 12 inches in length) and a longer hose connecting the nozzle assembly to the emergency disconnect (generally 10-12 feet long).

Some areas of the United States are mandated to have Refueling Vapor Recovery systems on dispensers. In these cases, fuel flows through an inner orifice while vapor returns through an outer annulus. Often components within in these systems have more restrictive areas that require increased liquid velocity during fuel transfer at 10 GPM.

Emergency Disconnect

Hose assemblies and the associated dispensers are protected with breakaway valves that shut off fuel flow should overextension of the hose occur, as shown in Figure 1 and 2. Breakaway construction dictates four directional changes, approximately 30 degrees each, in addition to restrictive fuel movement.

Husky Emergency Disconnect For standard fuel deliver system

Husky Emergency Disconnect End view – note annulus surrounding center deflector

Most fuel dispensing systems include a connector between the hose and nozzle that facilitates nozzle rotation without stressing the hose assembly. Various assemblies are used, some that allow 360-degree nozzle rotation while remaining in-line with the hose. Other swivel devices not only provide 360-degree nozzle rotation, but also move to adjust the angle of connection between the nozzle and hose. These latter devices not only have a restrictive orifice in the 360-degree swivel, they also cause fluid to experience several directional changes within short spans, thus create turbulence. Manufacturers indicate pressure drop across this type swivel is less than one pound per square inch at 10 gpm flow.

Some surfaces within observed swivels were machined smooth, while much of the surface area remained rough from casting. Also, these authors have noted significant increase in flex movement of swivel joints that have been installed and used for extended periods. Increased movement within a joint may indicate reduced electrical contact, thus loss of continuity.

Nozzle

Manufacturers' specifications indicate one of the greatest pressure losses occurs inside the nozzle assembly, generally around 10-psi loss when flowing 10-gallons per minute. Researchers disassembled and dissected nozzles to observe physical conditions that may lead to static generation. Those observations are detailed in this section.

Surfaces inside the OPW and Richards nozzles examined were not machined smooth, rather the relatively rough surface of casting remained. Within approximately six inches of entering the nozzle, fuel must pass through a valve opening and change direction approximately 80-degrees in the process. Once through the main control valve, fuel enters a chamber where it passes on either side of a cast column that vertically transcends the chamber, again changing directions in the process.

The greatest turbulence noted in nozzles, however, results from parts of the mechanism that assures automatic closure when a receiving container is filled. Automatic closure is activated through a pneumatic mechanism consisting of a diaphragm connected to the fill handle in the form of a pivot fulcrum. The pivot point remains in a position that permits the nozzle valve to activate under normal conditions, yet when the diaphragm rises, internal components cause the pivot point to drop, thus releasing the fulcrum, subsequently releasing the spring loaded primary valve to the closed position. A Venturi arrangement, through which the product passes, is paramount in the diaphragm's operation. The Venturi is connected to an opening near the nozzle end via a tube that passes through the nozzle orifice and to the diaphragm. When the nozzle is inserted into a container's air space, fluid movement draws air through small nozzles on the downstream side of the Venturi through an opening at the nozzle's end. When product occludes the opening, pressure reduction is transmitted to the diaphragm, which is pulled upward. This action drops the fulcrum point and causes automatic closure of the control valve. Manufacturer's data sheets indicate that flow of at least 3-gpm is required for the pneumatic mechanism to operate. Curt Fredrick of OPW Fueling Component's Technical Support division indicates that flow velocity of 15-feet per second across the Venturi is required to assure operation of the automatic closure feature within nozzles. It should be noted that the Venturi causes change of direction, turbulence and air induction, each a source of static electricity, all occurring within less than ½-inch distance of product travel. Figure 3 depicts four potential significant turbulence areas.

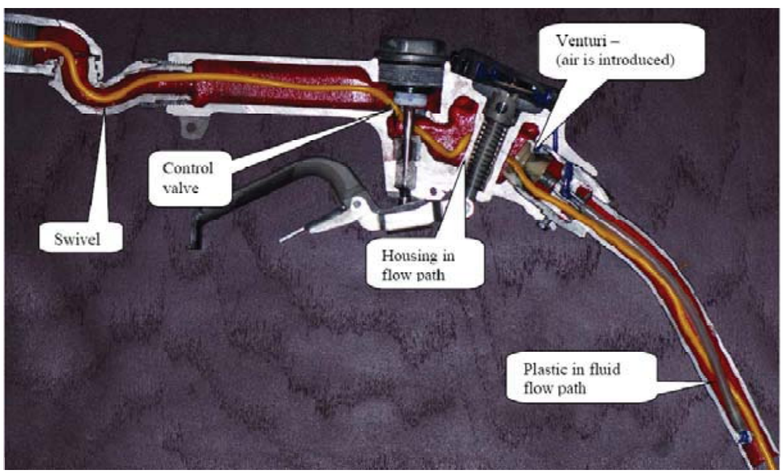


Figure 3 turbulence points in a fuel nozzle (OPW 11A)

NFPA 30A (2007) requires that nozzles used at dispensers that are controllable at remote locations, (Self Service) have features that prevent dispensing until the nozzle is activated. This requirement is intended to prevent flow of gasoline when a dispenser is activated remotely. Fuel can only flow the patron opens the nozzle. Methods of accomplishing this are to assure hold open latches are not usable or instillation of nozzles that require pressure from the dispensing system before the leaver will open the flow nozzle. Vapor Recovery Nozzles are made such that significant turbulence is present as fuel flows through.

Grounding Requirements

No requirement for equipment or dispenser grounding is noted in NFPA 30; however, NFPA 77 recommends grounding of all conductive and semi-conductive components in a manner equivalent to or surpassing requirements of those specified in NFPA 70, *The National Electric Code*, for electrical system grounding. Data indicates standard grounding methods are sufficient to dissipate static charge(s) generated during fuel transfer. It should be further noted; however, that all conductive and semi –conductive materials must have positive connection throughout the system and to the ground to assure static dissipation.

FLOW RATES and STATIC ACCUMULATION

Where grounding or bonding is not viable to reduce static accumulation, an alternative method to control static discharges is reduction of static charge generation through flow control. NFPA 77 recommends maintaining fuel flow rate below 3 feet-per-second (fps) when delivery is into an open-top vessel, until the nozzle is submersed in the fluid. Though the recommendation exists for tanker vehicles, similar charge separation occurs when dispensing gasoline into portable containers by splash loading through open tops. In Table 1, calculated fuel flow rates are correlated with liquid velocity at various points in common fuel delivery systems components.

	Flow velocity in feet per second				
GPM	3/4" hose	5/8" hose	Swivel connection	Nozzle inlet	Nozzle tip
10	7.26	10.46	11.82	10.77	12.92
9	6.54	9.41	10.63	9.69	11.63
8	5.81	8.37	9.45	8.61	10.34
7	5.08	7.32	8.27	7.54	9.05
6	4.36	6.27	7.09	6.46	7.75
5	3.63	5.23	5.91	5.38	6.46
4	2.90	4.18	4.73	4.31	5.17
3	2.18	3.14	3.54	3.23	3.88
2	1.45	2.09	2.36	2.15	2.58
1	0.73	1.05	1.18	1.08	1.29

Table 1

Writing in "*What Went Wrong?*" Tervor Kletz indicates that "filters or other restrictions should be followed by a long length of straight line to allow charges to decay" (Kletz, 1995) In describing precautions to prevent static discharges resulting from flammable liquid move.ment into cargo compartments, NFPA 30, *Flammable and Combustible Liquids Code*, offers the alternative of arranging piping in a manner that allows 30 seconds for charge relaxation prior to discharge after product passes through devices that produce static charges through turbulence.

Demonstrations of static accumulation during fuel transfer are provided by results obtained at Fowler Associates in November 2004. A 75 gallon capacity metal portable container tank with 12 volt pump was used to transfer fuel into a five (5) gallon plastic can for gasoline and a plastic automotive fuel tank. Resultant charge was measured with a non-contact meter. Results are indicated in Table 2.

Quantity (Gallons)	Rate (GPM)	Conditions	Charge (volts)
2.5	2.94	Can on pavement	1,080
2.5	5.17	Can on pavement	2,040
2.5	6.25	Can on pavement	2,350
2.5	3.66	Can elevated 28 inches	7,020
2.5	5.17	Can elevated 28 inches	8,170
2.5	6.25	Can elevated 28 inches	9,650
13.75	6.25	Fuel tank on pavement	20,000
13.85	6.25	Fuel tank elevated 28 inches	30000 +

Table 2

WARNINGS

Warnings required by NFPA 30A (2007) are posted at most self-service fuel dispensers that instruct patrons of proper procedures and conditions that should be avoided. Observation indicates these warnings are not standard and are often placed in obscure locations where patrons must seek the information. Font size is generally much smaller than advertisements and other information located in clear view during refueling events.

Fuel equipment manufacturers including OPW provide warnings on nozzle covers and some provide adhesive labels with more information for placement on fuel hoses. Placement of the additional warnings requires action by field personnel. A market exists for rebuilding nozzles that have been removed from service. Internal parts are replaced then the rebuilt nozzle is offered for sale. With rebuilt units, nozzle covers may not have proper warnings and no adhesive warnings provided as would be if the unit were new.

FINDINGS(s)

Ignition hazards result when vapors are released to the air and where static discharge is possible, most commonly at the nozzle.

All factors indicate the fires discussed in this research that involved portable containers occurred when fuel was transferred to portable plastic containers that had no method of dispersing static charges, when ambient humidity was extremely low, and that the dispensing nozzle was outside of the receiving container. These conditions caused static charge to accumulate, then discharge in a location where the vapor-air mixture would ignite. Of equal interest were ignitions involving automobiles where the nozzle remained in contact with the vehicle. No method was employed to assure static relaxation.

When ambient air has low moisture content, especially in colder conditions, dissipation of static accumulations is more difficult to assure. Static discharge was sufficient to ignite fugitive flammable vapors surrounding the dispensing nozzle.

The researchers reviewed possible reasons for increase in occurrence of static fires indicated by PEI (show in bold) and conclude the following.

1 **Changes in fuel chemistry**. *Though conductivity was greater in gasoline containing lead constituents, gasoline has never been listed as an electrically conductive liquid. Writings dating to the 1960's were examined and this conclusion was reached even then. It should be noted that Fowler states the static relaxation time for unleaded gasoline is much greater than that of leaded gasoline used in and before the 1970's. Blends with greater percentage of Ethanol are typically more conductive than those that contain no or low Ethanol.*

2 **Finish of the driveway or forecourt.**

3 **Tires being made with less carbon therefore are less conductive.**
For the purposes of discussion, these items are combined. Tire composition can affect static dispersion; however, conductance is very low at best. Static charges accumulated by air movement across the vehicle and by moving parts within the vehicle may be relaxed through more conductive tires and dispensing court pavement. Tires cannot provide grounding or bonding to assure effective connectivity in accordance with standards for fuel transfer however.

4 **Electrically insulated conductive components.** *PEI's article addresses fuel components within vehicles. It is very likely that conductive components are insulated from one another within composite or polymer systems and components. Such arrangements will preclude static dissipation, thus increase hazards. Insulated conductive components are possible within the dispensing system, as well as the vehicle storage system. Individual components may or may not assure conductivity and there is no assurance that dispensers are properly grounded or bonded.*

5 **Plastic filler inlets.** *Plastic components within vehicle fuel systems may present a hazard in that electrically charged fuel entering the system can collect then come in contact with a nozzle possessing opposite charges. Should the nozzle be removed at a point where a static discharge can occur in an atmosphere having proper vapor-air concentration, ignition is likely.*

6 **Customers re-entering their vehicles during refueling.** *Static generation on fabric through movement is a potential source for ignition, however, not the sole condition that generates these fires.*

The researchers conclude the following facts:

1) Use of plastic containers has increased to the point where plastic containers are used in greater numbers than are metal containers, especially by individuals. Because plastic containers cannot establish electrical bonds with dispensing equipment, static discharges are more probable.
2) Bedliners do not cause electrostatic charge separation in fuel containers however they do prevent conduction when metal cans are placed in the beds of vehicles equipped with the liners. Plastic containers have no conductivity regardless of finish in the bed of pickups or automobiles.
3) Fuel systems in automobiles often incorporate non-conductive components that prohibit electrical interconnectivity with the fuel hose assembly. This fact reduces the probability that an electrical bond is established between all components involved in fuel transfer.
4) High volume, self-service fuel delivery systems move fuel at rates capable of generating static charges. Dispenser and fill nozzle design also fosters static generation because they feature significant directional changes and restrictions within close proximity of fuel discharge points. Electrical charges developed during movement within the dispenser system do not have sufficient time to relax before discharge into receiving vessels. It is apparent that requirements of NFPA 30, Section 6.5.4.5, requiring equipment design and use to prevent electrostatic discharges, are not being met.
5) Lock-open devices, once prohibited by codes at self-service dispensers, are legal on self-service fueling dispensers when specific nozzle design is present; thus, humans may not remain at the same electrical potential as the nozzle, simply because they do not remain in contact. When reestablishing contact, difference in electrical potential increases the probability of an electrical discharge. Unless fuel flow has ceased, vapors sufficient for ignition are present. Requirement for nozzles that predicate valve closure before fuel flow is initiated results more from safety hazards brought by returning latched open nozzles to the dispenser than concern for leaving nozzles during refueling events (NFPA 30A, A.6.6.2, 2007).
6) High flow rates combined with non-conductive components in automobiles enhance the possibility that dispelled fuels experience charge separation that accumulates in the receiving vessel. In many cases, fuel in the receiving vessel has greatly differing electrical potential than does the dispensing equipment. When contact is approached, static discharge is likely. If that discharge occurs in an environment where the vapor-air concentration is within the product's explosive range, ignition will occur.
7) Increase in static fire frequency involving fuel-dispensing system may be attributed to change from metallic components (tanks and piping) that promote intrinsic grounding to plastic components that prohibit grounding. Systemic changes were promulgated for environmental concerns and did not account for safety issues related to static discharge. No codes were found during this research to indicate requirements that dispensers, hoses or nozzles be grounded.
8) Though plastic containers are relatively safe when used properly, extreme caution is needed. Filling containers rapidly and/or without proper precautions dictates that the probability of incidents occurring from discharges will prevail. Transfer to portable fuel containers almost always results in splash loading situations.
9) Though national alerts are correct in indicating that the ignitions can be reduced if containers are not filled when resting on plastic bedliners and/or on carpeted surfaces, the problem is much broader than indicated. Even when placed on moist, bare earth, dispensing fuel into plastic cans is likely to generate static charges capable of igniting escaping vapors. Ignitions that occur while fueling automobiles indicates that hazards

are not confined to inside vehicle bodies or plastic bedliners.

10) Re-entry into vehicles is a very preventable source of electrostatic charging that results in discharge in the form of an ignition source. Patron discharge before approaching the fuel transfer port of a vehicle can greatly reduce the possibility of discharge that will result in ignition. A more profound method of preventing fires from reentry is for attendants to stop fuel flow when patrons leave the point of fuel transfer. This action is predicated on NFPA 30A 9.4.3.1 (2007) which indicates the attendant shall supervise proper fuel transfer to control ignition sources.

11) Clothing worn by patrons is a source of electrostatic charging that is difficult to control. Immediate action to stop fuel flow when ignition happens is paramount in preventing serious injury. Attendants are responsible for stopping the flow in these situations.

10) It should be noted that automotive fuel dispensing systems
    a) Nozzles automatically shut off when the tip is covered with liquid thus flow from nozzles produces some degree of splash loading in all cases.
    b) Flow rates at many points in the system, especially in the nozzle exceed the 3 feet per second recommendation for reducing static generation.
    c) Nozzle design prohibits a long run of straight pipe to allow for static relaxation, especially the recommended 30-second relaxation time.

11) NFPA 30A requires attendants at Attended Self-Service locations supervise fuel transfer operations. Anecdotal evidence indicates that many, if not most, fuel dispensing occurs at locations where sales of other merchandise is of equal or greater importance (profit) than is gasoline. The authors frequently witness attendants at such locations engaged in transactions that prevent them from observing activities at fuel dispensers.
    Compliance with attendant requirements is imperative at attended self-service locations.

12) Instructions and warnings posted for patrons use are not standard and are often confusing. On retailer in North Carolina posted a sign that reads "Maintain your pump, We are not responsible for spills". When asked the meaning of Maintain Your Pump the manager indicated patrons should stay at the nozzle. Fortunately that location had removed hold-open devices, thus patrons are forced to remain in contact. Standard simple warnings that remind patrons rather than educate them should be posted conspicuously at dispensers. Educational campaigns, including print and mass media (television, radio and internet) should periodically instruct patrons of proper actions.

13) Use of point of sale credit / debit card readers facilitates fuel sales without actions on the part of retailers. In many cases, the authors have observed fuel dispensers remaining on after store hours, with site lights staying on, thus patrons can dispense fuel without attendants present. Unattended fuel distribution sites are permitted by NFPA 30A where local jurisdictions approve, however significant requirements are placed on the retailer. In many cases proper authorization for unattended distribution has not been obtained and requisite precautions are not present. This practice should cease.

RECOMMENDAITONS

Short of outlawing plastic fuel containers, and eliminating self-service fuel dispensers, one can use simple techniques to assure static dissipation or control of the charge.

1) NFPA 77 (2007) specifically states it does not apply to fueling of motor vehicles. Language of NFPA 77 exclude application to motor vehicle refueling however administrative language cannot exclude principles of physics that are present whenever

fuel is transferred. Change the standard to include fuel transfer to motor vehicles and portable containers in the recommendations contained in that document. Engineering principals contained within NFPA 407 appear very similar to those that should be instituted at automotive refueling sites.

2) Evidence of increased incidence of fires occurring during fuel transfer into plastic containers indicates NFPA 77 (2007) 7.13.6, *Hand Held Containers not Greater than 20L Capacity,* should be revisited to provide recommendations to alleviate static discharge hazards rather than exempt the vessels.
3) Conduct extensive analyses to determine which components are prone to generate static charges within currently used systems. Where possible, eliminate or reduce the static producing capacity of these components.
4) All components of fuel dispensing systems should be properly bonded and grounded. This will reduce, but not totally eliminate, hazards of static charge separation. Require periodic testing with applicable procedures to assure grounding capability exists at these instillations.
5) Removal of containers from the truck bed and automobile interiors increases capacitance within the liquid while simultaneously assuring that vapors do not accumulate into pools of ignitable vapors, however this action does not assure a fire will not occur. The potential for electrostatic discharge as containers are filled indicates the need for attendants at attended self-service transfer locations to stop flow to prevent fuel dispensing when patrons attempt improper actions.
6) Patrons should be instructed to place the dispensing nozzle into the plastic container and maintain contact with the container during the dispensing operation. Allow the metal nozzle to contact the fuel surface prior to removing the nozzle from the container. This method increases probability that any electrostatic charge developed during transfer is equalized within an area that is too rich to burn, therefore goes undetected.
7) Manufacturers of plastic fuel containers should explore manufacturing containers that have electrical conductivity or they should install metallic rings in the filler openings that include a metallic strip extending to lower regions of the container to assure bonding of fuel to the nozzle during dispensing.
8) Slow dispensing of fuel when filling portable containers is a method of reducing static. Reducing the fill rate to about $^1/_3$ or ½ of full capacity is more likely to prevent ignition. Reduction in fill rate to reach safe levels extends refilling of a 5-gallon tank to approximately 2 minutes rather than 45 seconds.
9) Patrons should assure that they stay in contact with dispensing nozzles, especially when atmospheric conditions are dry and cool. If a tingling sensation is detected, i.e. the hair begins to stand on one's arms, slow dispensing and leave the nozzle inside the vapor space for at least thirty seconds after the fuel flow stops.

OR

Patrons should place the nozzle for automatic delivery then not approach or touch the nozzle until the automatic closure has activated

10) Refueling vapor recovery is designed to prevent emission of 95% of gasoline vapors displaced during refueling operations. Evacuation of vapors prevents accumulations capable of igniting regardless of static discharge. Vapor recovery at all fuel dispensers has not proven cost effective according to Lewis Efird with United Oil of Gastonia (NC), costing more than $100,000 per service island; thus, changing to recovery type dispensers would likely force many small operators to go out of business. Efird also predicted change to this type system would not be popular with the general public (Personal Communication, . September, 2001) In the mid 1990's the United States Environmental Protection Agency (EPA) promulgated regulations dictating automobile install Onboard Refueling Vapor Recovery (ORVR) devices in all 2000 and later model passenger cars,

light trucks and sport utility vehicle. This design change has, and will continue to, significantly reduce the number of incidents due to less vapors emitting, however on older model vehicles the problem will persist. The following chart indicates mandated compliance with onboard vapor recovery systems.

Vehicle type	40% compliance	80% Compliance	100% compliance
Passenger Cars	1998	1999	2000
Light trucks (under 6000 lbs)	2001	2002	2003
Heavier trucks (6001-8500 lbs)	2004	2005	2006

11) Examine the possibility of positive connections during fuel transfer. Such systems would require vapor discharge to locations not prone to discharge ignition.

TIPS FOR INVESTIGATING FIRES AT FLAMMABLE LIQUIDS DISPENSING

When faced with a fire potentially ignited by static electricity at fuel dispensers, the investigator should consider the following:

1) Secure any video recordings that may be present at the location. Security cameras are present at many locations and may document the event. Secure these recordings early as they are often recorded over several times per day. Evaluate the images for information recorded by registers in addition to showing actions of attendants and patrons.
2) Determine product type, volume transferred and, if possible duration of the transfer. Collect and preserve samples of products involved in to facilitate analyses of those products.
3) Determine the vehicle's or container's fuel level when the ignition occurred.
4) Record statements of all witnesses relative to observations and time frames.
5) Identify all fabrics worn by all persons involved or near the ignition. Include both burned and unburned materials, including shoe construction. If possible, collect the clothing as evidence.
6) Document weather conditions including temperature, relative humidity, dew point, wind (speed and direction) and precipitation. Data concerning weather in recent days or weeks may prove helpful also.
7) Photograph and diagram all vehicles, containers and dispensing apparatus.
8) Identify the type of fuel dispenser, pump flow rate, distance to the pump, dispenser hose type(s) and size, break-away valve make and model, swivel make and model, nozzle make and model.
9) Specifically examine any filters within the fueling system, determining the make and model of that filter. Additional research is needed to determine size of the filtering system (in microns) and the amount of product that has been filtered. Collection of the filter(s) involved is strongly suggested. Analysis may indicate filter efficiency (microns) and contaminants that may contribute to electrostatic charge seperation.
10) Measure conductivity between all components and for the overall system between the dispenser and nozzle tip. Megohm meters are needed for making these measurements, electrical engineers; contracting firms and possibly colleges may provide access to these instruments. Assure components are dried before making these measurements as water from fire suppression will alter findings.
11) Identify the make, model and serial number of the vehicle.
12) Measure conductivity between the vehicle fuel filler opening and the fuel tank. It may prove helpful to conduct analysis of each connection along this system. Analysis of these findings should assist in determining possible sources of static generation and static discharge point(s).
13) Review websites of the ESD Journal (www.esdjournal.com), the American

Petroleum Institute (www.api.org) and the Petroleum Equipment Institute (www.pei.org) for recent developments in this area.

14) Report investigative observations and conclusions via the National Fire Incident Reporting System, to PEI's data base (www.pei.org) and to the ESD journal (autofires@esdjournal.com) for compilation and comparison on a national scale.

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