STATIC ELECTRICITY GENERATION AND IGNITION AT FUEL DELIVERY SYSTEMS

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A few years ago a fellow safety professional raised attention to a warning issued by Chevron U.S.A. regarding ignitions associated with dispensing gasoline into containers resting in pick-up truck beds equipped with plastic bedliners.[1] 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[2] (NISOH) issued instructions to always 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[3]."

These instructions raised many questions when published, and have become more intriguing, especially when queried by persons who experienced ignition of gasoline vapors by a static discharge. In two separate fire incidents that occurred in Gaston County, North Carolina during 1999, gasoline transfer into plastic containers were called into question as part of the ignition sequence.

Both incidents occurred during days when relative humidity was below 30%. The first case occurred as an individual transferred fuel from a plastic can into a lawn mower equipped with a plastic tank. Initial thoughts were that this ignition occurred from a hot exhaust. The individual, who stated he ran out of fuel, drove several miles to retrieve fuel, then experienced ignition as he was transferring the fuel into a unit that had been off for more than 20 minutes. In this case, the individual related that he was holding the fuel can's spout outside of the lawnmower's tank opening to allow observation of the tank level. As the tank neared full, an ignition occurred. The fire was quickly extinguished with no injury or damage.

In the other case, an individual was refueling five separate tanks, all in the bed of his pick-up truck, which was equipped with a plastic bedliner. This individual reported that he left the tailgate in the closed position. This individual noted that as he filled the final tanks, he observed hair on his hands and arms "standing up." At some point, an ignition occurred, generating a large fireball in the truck bed. All factors indicate that vapor build-up in the bed ignited. The individual suffered first and second degree burns on his lower legs and arms. Fire on his clothing was extinguished when he escaped the truck then practiced the stop, drop and roll method of extinguishment.

These incidents raised numerous questions: Why did these fires occur? Why is this type of incident now reported more frequently? Are plastic containers a safety hazard? And lastly, are the national alerts correct in indicating that the ignition can be prevented if containers are not filled when resting on plastic bedliners and/or on carpeted surfaces.

After significant research regarding ignitions involving portable containers, issues related to ignitions while and immediately following gasoline transfer to automobiles became more widely known. In late March, 2001 a young North Carolina girl was burned as she reached to cut the flow of gasoline from a dispensing nozzle inserted in her mother's SUV's fuel system. Reports indicate $20.00 worth of fuel had been dispensed prior to a static spark between the girl and the nozzle igniting vapors in the atmosphere surrounding the nozzle. The mother seeing the fire, removed the nozzle, still flowing, causing gasoline to splash on the child. Fuel flow was subsequently shutoff. Investigators consulted with Petroleum Equipment Institute (PEI) to learn more about this type of ignition. Based on this information, we reexamined a similar fire that occurred in February 1998 in Gaston County, North Carolina, where a static ignition was credited with igniting flammable vapors during the refueling of a 1995 Honda Civic[4].

PEI's web site confirms that PEI is aware of increased occurrence of static fires during refueling operations; however, they are not sure of the exact cause. Possible causes listed were

- **Changes in fuel chemistry**
- **Finish of the driveway or forecourt**
- **Tires being made with less carbon thus are less conductive**
- **Electrically insulated conductive components**
- **Plastic filler inlets**
- **Customers re-entering their vehicles during refueling**[5]

A separate report on PEI's site indicates 36 such ignitions between September 1999 and January 22, 2000. 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 "about half of the fires that have been reported to PEI involved the motorist re-entering the vehicle at some point during the refueling process."[6]

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.[7]

Research conducted by Steve Fowler with ESD, Inc. indicates ignitions caused by static discharges are a rising problem within not only the United States, but European nations also. The ESD Journal published by Fowler reflects numerous accounts of ignitions during fueling operations.[8]

These researchers were intrigued by 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. This divergence warranted exploration to determine if commonalities are present in these situations.

The National Fire Protection Association's (NFPA) Standard *NFPA 77, Recommended Practice on Static Electricity, 2000 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 these researchers relied on the document to provide understanding of static generation and control.

NFPA 30, *Flammable and Combustible Liquids Code* and NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages* provided 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 5.9.4 of NFPA 30 requires that all tanks, piping and machinery used to transfer fuel be designed and operated to prevent electrostatic ignitions.[9] These researchers hold that methods of static protection at motor fuel dispensers should be similar to that found at other fuel transfer locations.

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."[10]

STATIC ELECTRICITY

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[11]. 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."[12] 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…"[13]

"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[14]. It should be noted that a surface having a deficiency of one electron in 100,000 atoms is considered strongly charged.[15] Typically the charge is dissipated into 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 offers the possibility of sudden discharge, more commonly known as arcing. Voltages involved in static discharges are extremely high, while current (amps) remains relatively low[16]. 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,[17] It should be noted that accumulated electrostatic charges are much greater in low ambient humidity atmospheres (less than 30%) than can develop in higher humidity (greater than 65%).[18]

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 approximately 1,000 volts.[19]

STATIC DEVELOPMENT IN CLOTHING

Fabric movement does 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. When humidity was below 20% “dangerous voltages were produced on the body, even with cotton.”[20] This information indicates that gasoline vapors can be ignited by discharge of this energy.

Fowler estimates that approximately 80% of static related ignitions at fuel dispensers result from static accumulation on clothing discharging to the fueling system within an explosive atmosphere. He also indicated that electrostatic discharge involving human tissue may require up to three times the energy to achieve the MIE than if accumulated on other objects.[21]

FUEL TRANSFER

NFPA 77, 7.3.1 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." [22] Nonconductive liquids generate static charge that does not quickly dispel, ranging from a few seconds to a few minutes to relax.[23] Gasoline is listed as a non conductive, having varying conductivity <50 picosiemens per meter (pS/m),[24] thus charges generated inside a pipe during transfer may be transferred to the receiving vessel.[25] NFPA 407 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."[26]

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 the "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."

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, however, 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[27].

NFPA 77, *Recommended Practice on Static Electricity,* indicates that conductivity with 1,000,000 ohms[28] 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 even if the container is suspended by a grounded cable.[29]

One may assume that a static charge developed at the nozzle end of a fuel delivery system would transfer back, through piping and tanks, to the earth. NFPA 77 recommends that: "All parts of continuous all-metal piping should have resistance to ground that does not exceed 10 ohms."[30] However, modern systems involve tanks constructed of non-conductive or protected materials, connected to plastic, non-conductive piping, are prone to static development. However, within a closed system, no 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. NFPA 77 recommends as a minimum that all conductive couplings and components should be bonded and grounded,[31] and that total resistance to ground should not exceed 1,000,000 ohms.[32] Occupational Safety and Health Administration regulations prohibit employees from dispensing Class 1 flammable liquids into containers unless the nozzle and container are electrically interconnected.[33] This essentially prohibits use of plastic fuel containers in the workplace.

NFPA 30 specifically indicates that, though conductive hose assemblies are required, bonding provided by intrinsic conductivity in these hose assemblies is not sufficient to assure bonding for aircraft refueling operations, rather a separate bond cable is required to connect the delivery vessel and the receiving vessel.[34] Additional bond wires are required to assure equal electrical potential between nozzles and that aircraft.[35] 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.[36] 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.

It should be noted that high voltage 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 that wherein static discharges would not generate sufficient heat to ignite vapors.[37]

CONDUCTIVITY

Directives dictate removing containers from plastic bed liners before refueling, but why? NIOSH reasons this “provides path to dissipate static charge to ground,”[38] while Chevron indicated that the bedliner prevented static charges from reaching ground.[39] 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, today's more popular plastic cans pose differing concerns, as they are not conductive.[40] 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.

Gasoline is listed as a non-conductive material,[41] 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.

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.

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.

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.

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.

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 attached to couplings to provide an electrically conductive path from end to end. Modern systems are 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).

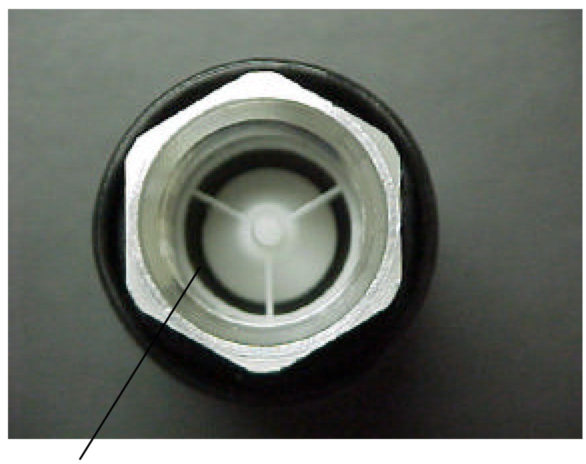
Emergency Disconnect

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.

Figure 1

Husky Emergency Disconnect

Figure 2



Husky Emergency Disconnect
End view – note annulus surrounding center deflector

Swivel

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

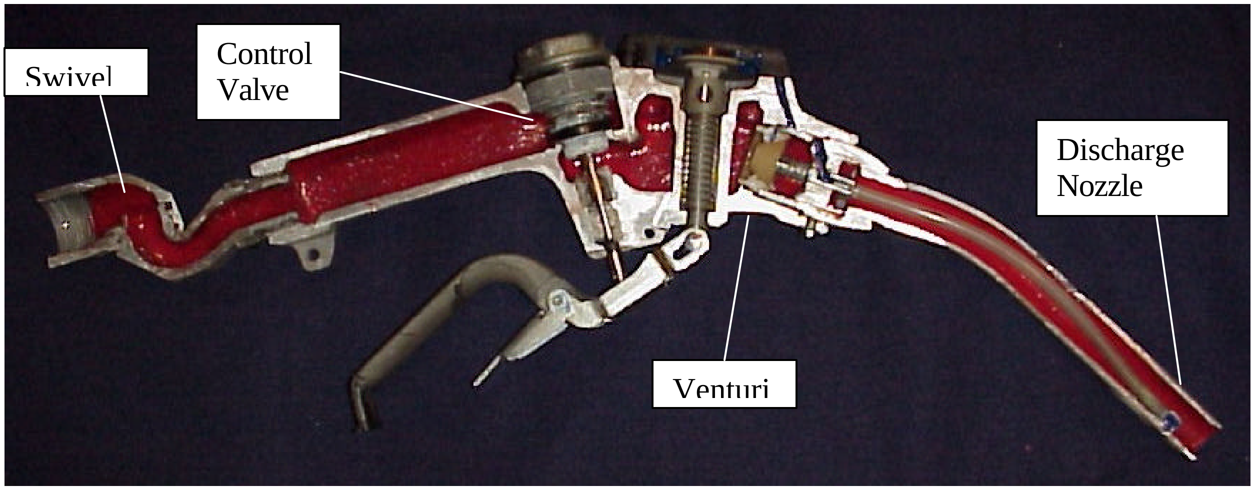
Manufacturers' specifications indicate one of the greatest pressure losses occurs inside the nozzle assembly, generally around 10-psi loss when flowing 10-gallons per minute.[42] Researchers disassembled and dissected nozzles to observe physical conditions that may lead to static generation. Those observations 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.[43] 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



Significant turbulence points in a fuel nozzle (OPW)

<u>Grounding requirements</u>

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 fuel.[44] 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 end
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."[45] In describing precautions to prevent static discharges resulting from flammable liquid movement 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.[46]

FINDINGS

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 a 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.

- **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.*[47] *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.*[48]

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

- **Tires being made with less carbon therefore are less conductive.**

  For the purposes of discussion, these items are combined. Steve Fowler indicated that tire composition can affect static dispersion;[49] *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.*

- **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.*

- **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.*
- **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) 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.

3) 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 Section 5-9.4 of

NFPA 30, requiring equipment design and use to prevent electrostatic discharges, are not being met.

4) Lock-open devices, once prohibited by codes at self-service dispensers, are now legal on self-service fueling dispensers; 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.

5) 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.

6) The single greatest factor in increased incidence of static fires involving fuel-dispensing systems is 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 that indicate requirements that dispensers, hoses or nozzles be grounded.

7) 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.

8) 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 occurred while fueling automobiles indicates that hazards are not confined to inside vehicle bodies or plastic bedliners.

9) Though static generation on clothing is a cause, equal concern must be placed on the probability that static is building within the fuel delivery system, charging metallic parts of the nozzle and the automobile. Near contact between a human or other objects holding divergent electrical potential becomes a point for discharge when sufficient electrical differential exists.

It is possible that discharge can occur when a nozzle with one electrical potential is being removed from a product with an opposite potential. When electrical discharge occurs in an atmosphere with explosive vapor-air mixtures, ignition will result.

10) It should be noted that automotive fuel dispensing systems

a) Automatically shut off when the nozzle is covered, thus the submersion alternative is not valid.

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.

RECOMMENDAITONS

So what's the solution? Short of outlawing plastic fuel cans, and eliminating self-service fuel dispensers, one can use simple techniques to assure static dissipation or control of the charge.

1) NFPA 77 specifically states it does not apply to fueling of motor vehicles. Change the standard to include fuel transfer to motor vehicles and portable containers in the recommendations contained in that document.[50] Evidence of increased incidence of fires occurring during fuel transfer into plastic containers indicates that section 7.13.6, *Hand Held Containers not Greater than 20L Capacity,*[51] should be revisited to provide recommendations to alleviate static discharge hazards rather than exempt the vessels. Engineering principals contained within NFPA 407 appear very similar to those that should be instituted at automotive refueling sites.
2) 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.
3) All components of fuel dispensing systems should be properly bonded and grounded. This will reduce, but not totally eliminate, hazards of static development. Require periodic analyses to assure grounding capability exists at these instillations.
4) Removal of containers from the truck bed and automobile interiors reduces capacitance within the liquid and assures that vapors do not accumulate into pools of ignitable vapors, however this action does not assure no fire will occur.
5) Persons 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 static charge develop during transfer is equalized within an area that is too rich to burn, therefore goes undetected.

6) Manufacturers of plastic fuel cans 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.

7) 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.

8) Redesign dispensing components so that larger orifices are throughout reducing flow velocity. Federal design specification revision is required as automobile fuel tank openings dimensions are restricted by federal code. This restriction was enacted when automobiles were transitioning from leaded to unleaded fuel; however, are no longer applicable as leaded fuel is not available in the United States. Reverting to larger openings would permit larger dispensers; thus, reducing product velocity. Changing from the current standard nozzle for gasoline to nozzles designed for diesel fuel would reduce flow rate 45% at 10 gpm (from 12.92 fps to 7.26 fps). This change may not be readily accepted by the petroleum industry because the automatic closure feature on currently available nozzles utilizes flow velocity to draw air through the Venturi as part of a pneumatic closure system. Reducing velocity would require nozzle redesign.

9) Persons 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.

10) Install fuel delivery systems equipped with vapor recovery at all fuel dispensers where individuals may utilize the system. Evacuation of vapors prevents accumulations capable of igniting regardless of static discharge. Lewis Efird with United Oil of Gastonia explained this move would prove very costly, more than $100,000 per service island; thus, will likely cause many small operators to go out of business. Efird also predicted change to this type system would not be popular with the general public[52]

11) Examine the possibility of positive connections during fuel transfer. Such systems would require vapor discharge to locations not prone to discharge ignition. Such systems would be needed only in regions not requiring vapor recovery type fuel dispensers.

12) Explore the possibility of adding constituents into gasoline formulations that reduce static development and/or decrease time required for charge relaxation.

INVESTIGATING FIRES INVOLVING 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 videotapes that may be present at the location. Security cameras are present at many locations and may document the event. Secure these tapes early as they are often recorded over several times per day.

2) Determine product type, volume transferred and, if possible duration of the transfer.

3) Determine the vehicle's fuel level when the ignition occurred.

4) Record statements of all witnesses relative to observations and timeframes.

5) Identify all fabrics worn by all persons involved or near the ignition. Include both burned and unburned materials, including shoe construction.

6) Document weather conditions including temperature, relative humidity, dew point, wind (speed and direction) and precipitation.

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. 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.

9) Measure conductivity between all components and for the overall system between the dispenser and nozzle tip.

10) Identify the make, model and serial number of the vehicle.

11) 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).

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.

Above all, please report your observations and conclusions via the National Fire Incident Reporting System and to the ESD journal (autofires@esdjournal.com) for compilation and comparison on a national scale.

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