Standard Guide for
Generation and Dissipation of Static Electricity in Petroleum Fuel Systems[1]

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INTRODUCTION

Every year a number of fires and explosions in petroleum product systems are attributed to spark ignition from accumulated static electricity. Such fires require a flammable hydrocarbon/air mixture and an ignition source. Safety practices can concentrate on the elimination of either factor, but this guide provides a general background on how electrostatic charges are formed and how they may be prevented or dissipated.

A subtle and often misunderstood feature of these incidents is the possible accumulation of hazardous electrostatic charges in systems which are properly bonded and grounded. This can occur because refined hydrocarbon fuels have low electrical conductivities and electrostatic charges may be retained within the fuel and on its surfaces.

1. Scope

1.1 This guide describes how static electricity may be generated in petroleum fuel systems, the types of equipment conducive to charge generation, and methods for the safe dissipation of such charges. This guide is intended to increase awareness of potential operating problems and hazards resulting from electrostatic charge accumulation.

1.2 This guide is not intended to provide specific solutions but indicates available techniques the user may wish to investigate to alleviate electrostatic charges. This guide does not cover the effects of stray currents or of lightning, either of which can also produce sparks leading to fires or explosions.

1.3 This guide is not intended to address detailed safety practices associated with static electricity in petroleum product systems.

1.4 The values in SI units are to be regarded as the standard. The values in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D56 Test Method for Flash Point by Tag Closed Cup Tester
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)
D396 Specification for Fuel Oils
D910 Specification for Leaded Aviation Gasolines
D975 Specification for Diesel Fuel Oils
D1655 Specification for Aviation Turbine Fuels
D2276 Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
D2624 Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
D2880 Specification for Gas Turbine Fuel Oils
D3699 Specification for Kerosine
D3948 Test Method for Determining Water Separation Characteristics of Aviation Turbine Fuels by Portable Separometer
D4306 Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination
D4308 Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter
D5191 Test Method for Vapor Pressure of Petroleum Products (Mini Method)

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D5452 Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration

D6615 Specification for Jet B Wide-Cut Aviation Turbine Fuel

2.2 *National Fire Protection Association (NFPA) Standards:*[3]

NFPA Standard No. 30 Flammable and Combustible Liquid Code

NFPA Standard No. 407 Standard on Aircraft Fuel Servicing

2.3 *Canadian General Standard Board (CGSB) Specification:*[4]

CAN/CGSB 3.6 Regular Sulphur Diesel Fuel

CAN/CGSB 3.517 Automotive Low Sulphur Diesel Fuel

2.4 *British Standards Institute (BSI) Standard:*

BS 5958 (Part 2) Recommendations for Particular Industrial Situations[5]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bonding, v*—the practice of providing electrical connections between conductive parts of a fuel system to preclude voltage differences between the parts.

3.1.2 *bottom loading, v*—the practice of filling transport compartments by pumping fuel through a bottom inlet.

3.1.3 *charge accumulation, n*—the increase of electrostatic charges in a tank, compartment, or liquid resulting from a rate dissipation slower than the rate of charge delivery by the incoming product.

3.1.4 *charge generation, v*—the creation of electrostatic charges in a liquid due to the separation of ionic species during liquid flow.

3.1.5 *charge relaxation, n*—the decrease of electrostatic charges with time.

3.1.6 *combustible liquid, n*—a liquid having a flash point at or above 38°C (100°F) (See Test Methods D56 and D93).

3.1.6.1 *Discussion*—Subdivisions of this classification will be found in NFPA Standard No. 30.

3.1.7 *conductivity, n*—the reciprocal of electrical resistivity, the capability to transmit electrostatic charges normally expressed in picoSiemens per metre (pS/m) for petroleum products.

3.1.7.1 *Discussion*—Conductivity has also been expressed in conductivity units (C.U.) where I.C.U. = 1 pS/m = 1×10^{-12} Ω^{-1} m^{-1}.

3.1.8 *conductivity improver additive, n*— a material added to a fuel in very small amounts to increase its electrical conductivity and thereby reduce relaxation time.

3.1.8.1 *Discussion*—Conductivity improver additives are also known as static dissipator additives (SDAs) or antistatic additives.

3.1.9 *flammable liquid, n*—a liquid having a flash point below 38°C (100°F) (see Test Methods D56 and D93) and having vapor pressure (Test Method D323 or D5191) not exceeding 276 kPa (40 psia) (see NFPA Standard No. 30).

3.1.9.1 *Discussion*—The definition of flammable is currently under discussion by the UN Committee of Experts on the Transportation of Dangerous Goods.

3.1.10 *grounding, v*—the practice of providing electrical continuity between a fuel handling system and ground or earth.

3.1.11 *high vapor pressure product, n*—a product having a vapor pressure above 31 kPa (4.5 psia) (**1**).[6]

3.1.12 *intermediate vapor pressure product, n*—a product with a vapor pressure below 31 kPa (4.5 psia) and a flash point below 38°C (100°F) (**1**).

3.1.13 *low vapor pressure product, n*—a product with a flash point above 38°C (100°F) (**1**).

3.1.14 *relaxation time, n*—the time required for a charge to dissipate to 36.8 % of the original value (**2**).

3.1.15 *residence time, n*—the length of time after a charge is generated that a product remains in piping or a closed vessel.

3.1.16 *splash filling, v*—the practice of allowing fuel to free-fall or to impinge at high velocity on a tank wall while loading a compartment.

3.1.17 *static discharge, v*—the release of electrical energy in the form of a spark or corona discharge across a gap between surfaces of differing voltage.

3.1.18 *switch loading, v*—the practice of loading one type of product into a tank or compartment which previously contained a different type of product.

3.1.18.1 *Discussion*—When involving handling safety, switch loading often refers to loading a low vapor pressure product into a tank or compartment previously containing a high vapor pressure product. A flammable vapor in the ullage space is likely to result.

3.1.19 *top loading, v*—the practice of filling transport compartments through an open dome at the top of the transport.

3.1.20 *ullage (vapor) space, n*—the space between the liquid surface and the top of the tank or compartment containing the liquid.

3.1.21 *unbonded charge collector or accumulator, n*—unbonded, conductive objects which concentrate electrical charges.

3.1.21.1 *Discussion*—These unbonded charge collectors may be objects floating on the surface of the charged liquid or objects such as gaging tapes lowered toward the charged surface. The high conductivity of metallic charge collectors permits the rapid discharge of accumulated charges.

4. Significance and Use

4.1 Pumping, filtering, and tank filling of petroleum products, particularly refined distillates, can cause the generation and accumulation of electrostatic charges and can result in

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[3] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02269-9101.

[4] Available from Canadian General Standard Board, Ottawa, Canada.

[5] Part 2 of British Standard Code of Practice for Control of Undesirable Static Electricity, available from British Standards Institute, 2 Park St., London, England WIA2B5.

[6] The boldface numbers in parentheses refer to the references at the end of this standard.

static discharges capable of causing fires and explosions. This guide provides an overview of the factors involved in the generation of such electrostatic charges. Methods are described for the alleviation of the problem, and cited authoritative references contain more details.

4.2 This guide is not intended to provide operating or safety rules for the handling of petroleum products to avoid electrostatic hazards.

5. Background

5.1 *Ignition Principles:*

5.1.1 For ignition to occur, it is necessary to have an ignition source of sufficient energy and a mixture of fuel and air in the flammable range. The boundaries of the flammable range are defined by the lean and rich limits. Below the lean limit there is not enough hydrocarbon vapor to sustain combustion, whereas above the rich limit there is not enough oxygen. The mixture temperature and pressure and the fuel characteristics, including boiling range and vapor pressure, determine the amount of a given fuel which is vaporized and therefore establish the flammability of the mixture. Normally these limits are measured under equilibrium conditions with the fuel partially or completely vaporized. However, ignitions have occurred below the lean ignition limit when the fuel was in the form of a foam or spray. Also, systems are not normally in equilibrium when there is sufficient fuel flow to generate electrostatic charges. Turbulence in the vapor space can lead to unexpected flammable air-vapor mixtures in localized areas. Equilibrium flammability limits can therefore be used only as rough guidelines of flammability.

5.1.2 The second requirement for ignition is a static discharge of sufficient energy and duration. Discharges occur when the voltage across a gap exceeds the breakdown strength of the fluid or air in the gap. Minimum energy requirements vary widely depending on the nature of the spark, the configuration of the spark gap and electrodes, nature of materials, and other factors. There is no doubt that sparks due to static electricity in petroleum systems can have sufficient energy to ignite flammable mixtures when they occur in the vapor space. Discharges from highly charged fluids are known to penetrate plastic tubing.

5.2 *Charge Generation*—Whenever a hydrocarbon liquid flows with respect to another surface, a charge is generated in the liquid and an equal but opposite charge is imposed on that surface. This charge is attributed to ionic impurities present in parts per million or parts per billion quantities. At rest the impurities are adsorbed at the interface between the fuel and the container walls, with one part of the ionic material having a strong attachment for the fuel or the container. Under these conditions, there is no net charge on the fuel. However, when the fuel flows, one set of charges is swept along with the fuel while the opposite charges which accumulate along the wall surfaces usually leak to ground. This charge separation results in a rise in voltage in the moving fuel.

5.3 *Charge Relaxation*—When charged fuel enters a tank, a substantial voltage difference may be produced between the surface of the liquid and the tank walls and this may result in a static discharge. The voltage difference is limited by charge dissipation/relaxation processes which occur both in the pipework downstream of strong charge generating elements and in the tank itself. Relaxation in the pipework reduces the amount of charge that reaches the tank while relaxation in the tank reduces the voltage produced by a given amount of inlet charge. Under most practical loading conditions, the voltage generated by a given inlet charge density is proportional to the relaxation time of the fuel. This relaxation time is inversely proportional to the conductivity and is approximately 20 s when the conductivity is 1 pS/m. The conductivity of hydrocarbon fuels is highly variable as a result of natural product differences, commingling, or the use of additives. Products not containing additives, including diesel fuels, may have conductivities of less than 1 pS/m but many modern additive packages (not just static dissipator additives) provide considerably increased conductivity, possibly up to several hundred pS/m or more. The relaxation time can therefore be anything form a fraction of a second to a number of minutes. It has been found that the reduced relaxation time produced by increasing the conductivity more than compensates for any increase in charge generation that may occur. The highest voltages and electrostatic ignition risks are therefore associated with low conductivities. Unless conductivities are controlled, the possibility of encountering low conductivity product should be allowed for when defining safe loading procedures (**3**, **4**).

6. Practical Problems

6.1 Certain switch loading operations, such as loading of diesel fuel into a truck which previously carried gasoline and still contains vapors or liquid gasoline, are especially dangerous. The combination of a flammable vapor space and charged diesel fuel presents a potential explosion hazard if an electrostatic discharge occurs. Analyses (**5**) of past tank truck accidents reveal that switch loading or splash filling, or both, account for 80 % of static-initiated explosions. More information on the hazards of flammable atmospheres formed during switch loading will be found in 7.6.

6.2 Microfilters and filter-separators are prolific generators of electrostatic charges. The type of ionic impurity in the product as well as the type of surface determine the magnitude and polarity of separated charges that are swept away in the flowing stream. Many additives in fuel increase the level of charge generation upon filtration, although in the case of static dissipator additives this is more than compensated by enhanced charge dissipation. Most common filter media such as fiberglass, paper, and cloth as well as solid adsorbents are potent charge generators. When carrying out operations such as meter proving that involve the use of temporary or mobile equipment, care should be taken not to introduce filters without adequate residence time (**6**) .

6.3 Flow rate is an important parameter in charge generation because the delivery of more fuel per second delivers more charge per second (that is, a larger electrical current). This results in higher surface voltages. Also, an increased flow velocity frequently generates more charge per unit volume of fuel.

6.4 Certain types of pumps, such as centrifugal or vane pumps, can be prolific charge generators due to high exit velocities at impellers.

6.5 Splash filling of a storage tank or tank trunk represents another mode of charge generation. Spraying of droplets causes charges to separate, leading to the development of both charged mist and foam as well as charge accumulation in the liquid. If the drop tube in a fill line fails to extend to the bottom of a receiving vessel or below the liquid level, splashing will result.

6.6 Conductive objects exposed to charged fuel become charge accumulators if unbonded to the receiving vessel. In cases where an incentive discharge has taken place, an unbonded charge collector is likely to have been present because a charged hydrocarbon surface by itself makes a poor electrode. A high potential is needed form hydrocarbon surfaces to develop a spark with sufficient energy for ignition, but a conductive object (such as a metal can or insulated fitting) in contact with a hydrocarbon at lower potential can more readily carry accumulated charge to the sparking point and provide an incendiary spark at much lower potential. Conductive objects are not always metal. A piece of ice can act as a charge collector and a surface pool of free water can accumulate a high surface charge. Objects dropped into a tank such as pencils, flashlights, or sample thief parts are a source of dangerous accumulators.

6.7 Fueling aircraft, where the fuel is highly charged following the necessary fine filtration, can create a difficult electrostatic situation. Hose and manifold residence time is usually too short to provide a significant amount of charge relaxation. However, accidents due to electrostatic ignitions have been rare compared to truck loading explosions primarily because aircraft fuel is usually bottom-loaded, aircraft have smaller compartments, and aircraft fuel tanks contain protrusions which tend to encourage low-intensity corona rather than the more incendiary spark discharges. The nonflammability of Jet A or A-1 at most fueling temperatures as well as the use of conductivity-improving additives are other alleviating factors.

6.7.1 While fueling aircraft, bonding between the aircraft and the fueler is required to prevent a voltage differential from developing between them. Grounding is not required (see NFPA Standard No. 407). Grounding does not provide any additional benefit in a properly bonded system during fueling operations (**5**).

6.8 Filling a large storage tank or tanker compartment can lead to charge generation even when splash loading is avoided. The movement of air bubbles or water droplets through the bulk fuel as the tank contents settle is a charge generation mechanism and can cause a high charge level to accumulate in a low-conductivity fuel. Charge generation by settling can persist for many minutes after filling ceases (see 7.5.2).

6.9 Filling an empty filter-separator vessel can create an electrostatic hazard if liquid is not introduced slowly. Fuel filling an empty vessel at high rates will cause charges separated on the elements to develop high voltages and discharge through the vapor space which contains air. In virtually all such cases, filter elements exhibit burn marks due to low-order combustion of fuel foam. Explosions which have ruptured the vessel have occurred when flammable mists or vapors were present. Residence time is extremely short and even if the fuel contains conductivity improver additive, the raised conductivity may be insufficient to reduce potentials by enough to avoid static discharges.

6.10 Sampling a low-conductivity fluid into a plastic container poses a special problem because it is obviously impossible to bond the filling line to the plastic. Pouring from or shaking a plastic receptacle containing low-conductivity fuel will also cause charges to separate.

6.11 Coatings which are normally applied on steel surfaces for corrosion protection do not affect the electrical behavior of charged fuels; thus, coated tanks and pipes act similarly to bare metal.

7. Possible Approaches to Electrostatic Charge Alleviation

7.1 A number of approaches to alleviate electrostatic charging problems are described in Refs (**1**, **2**, **7**, **8**, **9**). These approaches try to reduce or eliminate charge generation or accumulation, eliminate the possibility of spark formation, or change ullage space composition out of the flammable range. Summaries of a number of such techniques follow. Greater detail will be found in the cited references. (**Warning—**None of the following approaches eliminates the need for proper bonding and grounding, which is necessary to prevent voltage differences from developing on the system (piping, receiving tank, and so forth) or on unbonded objects within a tank or compartment. For proper bonding and grounding procedures, consult Ref (**2**) and BS 5958 (Part 2).)

7.2 *Line Velocity Reductions*—Although earlier practice was to keep velocities below 5 to 7.5 m/s, later work has shown that other factors such as the volume of the tank being filled, the fill pipe diameter, the fuel conductivity, and the mode of filling (top or bottom loading) need to be considered. Current thinking is to generally keep velocities below 7 m/s and, in addition, to impose further restrictions as applicable depending on the factors previously listed. For detailed recommendations the reader is referred to Refs (**1**, **10**) and BS 5958 (Part 2). The reduction of flow rate through a filter may not reduce charge density significantly but it will reduce current flow and will increase residence time downstream of the filter.

7.2.1 In systems where switch loading might occur, valves, meters, pumps, and other fittings may result in flow restrictions which give significantly higher velocity past these surfaces than estimated for a system's riser arm and hosing. It is suspected that the higher velocities in these fittings might increase electrostatic charging and they should be located as far as practical upstream of inlets to vessels.

7.3 *Relaxation Time:*

7.3.1 Even at the lowest conductivities, where the risk of static discharge is greatest, the charges produced by pipe flow are normally safely dissipated within the receiving tank if the velocity limits mentioned in 7.2 are adhered to—this is the reason for choosing these limits. At higher fuel conductivities (see 8.1.1), the reduction in relaxation time more than compensates for any increased charge generation that might occur; consequently, the voltages generated inside tank compartments are lower.

7.3.2 During tank truck loading or storage tank filling, high charge densities caused by filters or similar flow obstructions should be relaxed back to normal pipe charging levels by providing at least 30-s residence time downstream of the filter before the product reaches a loading arm or fill pipe. For products with conductivities less than 2 pS/m (or where the actual or possible minimum conductivity at field temperature conditions is unknown) longer residence time may be required (**1**).

7.3.2.1 The residence time for aircraft fueling has been substantially less than 30 s. Residence times as low as 3 to 7 s after a system containing water absorbing media monitors and 5 to 21 s after filter coalescer elements have been reported (**11**). These have been found by experience to be satisfactory for the particular conditions encountered in existing aircraft fueling systems (see 6.7). Care should be taken in fueling aircraft so that new designs or materials in the ground handling systems do not markedly change charging tendency or residence times compared with those known to be safe at that site.

7.3.3 Charge relaxation may also be required under circumstances where flow has stopped but a charge has been created before flow stoppage. Thus, relaxation time is required in the Particulate Contaminant Test for Aviation Fuel (Test Method D2276), where electrical charging has been caused by the membrane filter used in the test. A 1-min wait is therefore recommended for charge relaxation before disassembling the housing which holds the test capsule. The same waiting period is appropriate for the case of the plastic sample container mentioned in 6.10. Test Method D5452 contains laboratory filtration procedures which have been modified to reduce electrostatic hazards. A much longer waiting time, possibly up to 30 min, is recommended before sampling large storage or ships' tanks (**1**). This is based on measurements taken in large tanks which have shown a slower decay of field strength than would be expected by normal charge relaxation. The slow decay may be due to further charging by the settling of charged particles of water, dirt, or other materials.

7.4 *Elimination of Splash Loading*—When trucks are top-loaded with overhead lines, that is, drop tubes, these lines should reach to the bottom of the compartment to avoid dropping the product with subsequent splashing. When bottom or pressure loading is used, the fuel inlet should be baffled to avoid spraying fuel all over the compartment during initial filling. Electrostatic risks are greatly reduced by using a loading velocity of less than 1 m/s until the fill pipe inlet is completely covered. This practice is applicable also to storage tank filling and ship loading where it minimizes the disturbance of water bottoms and sediment.

7.5 *Elimination of Unbonded Charge Collectors:*

7.5.1 Unbonded, loose objects in a compartment or tank are a major hazard and must be eliminated by periodic compartment inspection to ensure proper cleanliness. Care should also be taken not to design in unbonded charge collectors such as wire bundle clamps or fittings on fuel hoses.

7.5.2 A gaging tape or sample container can be a charge collector if lowered into the fuel before charges have relaxed to a safe level. At least 1 min should elapse between the stoppage of flow and the lowering of any object into a small compartment (**1**). A much longer waiting time, possibly up to 30 min, is recommended for large storage or ships' tanks (see 7.3.3).

7.6 *Elimination of Flammable Vapors in Ullage Spaces*—When compartments or tanks are consistently used for either high- or low-vapor pressure products, the ullage space in these compartments is either too rich or too lean to be flammable. However, when switch loading from high- to low-vapor pressure products occurs, the ullage space frequently ends up in the flammable range before becoming either too rich or too lean. Such switch loading has therefore resulted in many loading fires or explosions and the practice is best eliminated. Where this is not feasible or where intermediate vapor pressure products such as crude oil or Jet B are handled, either ullage oxygen content should be reduced to render the compartment nonflammable or filling rates should be restricted to prevent the occurrence of hazardous potentials (see 7.2). Large crude-carrying tankers routinely use filtered flue gas inerting, but nitrogen or carbon dioxide can be employed for the same purpose in smaller systems. However, system operation should be checked to ensure the nonflammability of the ullage space. It may also be necessary to establish that the resultant dissolved gases do not cause operating problems later through product contamination or evolution at reduced pressures.

7.7 *Use of Low-Charging Filters*—Depending on the filter material, different filters with the same filtration performance may charge petroleum products to radically different electrical levels. To identify the problem and to select low-charging filters, a procedure for determining the charging level of aviation fuel filter-coalescers and separator elements has been developed (**12**).

NOTE 1—However, tests on a single fuel/material combination may not be definitive in determining the maximum charging potential of that material. The use of low-charging filters cannot substitute for the other precautions listed earlier.

7.8 *Use of Additives*—The use of additives to control the effects of electrostatic charging is covered in Section 8.

8. Additives

8.1 *Mechanism of Operation:*

8.1.1 Conductivity improver additives increase the conductivity of fuels and increase the rate of charge dissipation, that is, decrease the charge relaxation time, resulting in a significant reduction or elimination of electrostatic discharges. The additives are hydrocarbon-soluble polymers, metallic salts, or nonmetallic salts. These additives are designed for use at low concentrations with minimal effects on other fuel properties. One additive, approved for use in aviation fuels, is listed in Specifications D1655, D6615, and D910; this additive is suitable also for many non-aviation fuels, as defined in Specifications D396, D975, D2880, D3699, and other hydrocarbons. Other additives suitable for non-aviation fuels are also available. These additives do not reduce the degree of electrostatic charging and can cause an increase in charging depending on specific conditions. However, a suitable increase in conductivity in virtually all cases results in an increased rate of charge dissipation and thereby a significant reduction or elimination of electrostatic discharges. In the one case mentioned in 6.9, filling an empty filter-separator vessel, residence time is extremely short and is insufficient for charge relaxation; in this particular circumstance, the increase in conductivity conferred by a conductivity improver additive is ineffective in overcoming any increase in charge generation.

8.1.2 Use of conductivity additives has significantly reduced the occurrence of ignitions caused by static in various petroleum handling systems; for example, during switch loading from high or intermediate vapor pressure products to low vapor pressure products (6.1). There are no specific literature references for the extent to which flow rate (7.2.1) and relaxation time (7.3.2) guidelines are affected. When conductivity additives are used to alleviate electrostatic hazards, it is essential that great care is taken to ensure fuels are always treated to obtain an appropriate conductivity. All other practices recommended to reduce electrostatic hazards, such as bonding, must still be followed.

8.2 *Method of Measurement:*

8.2.1 Refined hydrocarbons have very low conductivity compared to other liquids; for example, jet fuel may have a conductivity 100 million times lower than that of water. Two ASTM test methods are available to measure conductivity. Test Method D2624 covers field test methods and Test Method D4308 describes a high precision laboratory test method. Some of the equipment listed in Test Method D2624 can measure conductivity in situ.

8.2.2 Special sample containers are needed to avoid additive adsorption on container surfaces or desorption of container materials which may affect conductivity. Suitable containers are described in Practice D4306. These effects can be minimized by measuring conductivity directly in the system or promptly after sampling. Conductivity can also be affected by exposure to light and clear containers should be avoided.

8.3 *Conductivity Limits:*

8.3.1 Conductivity limits for aviation fuels are described in Specifications D1655 (Jet A and Jet A-1 aviation turbine fuels), D6615 (wide cut aviation turbine fuel), and D910 (aviation gasolines) although none of these specifications contain a mandatory minimum requirement for electrical conductivity. When conductivity improver additive is requested by the customer for the purpose of ensuring rapid charge relaxation, the conductivity should be between 50 and 600 pS/m under conditions at the point of delivery meeting Specification D1655 and between 50 and 450 pS/m under conditions at the point of delivery for fuels meeting Specifications D910 and D6615. These limits, and hence conductivity improver additive addition, are mandatory for Jet A-1 supplied in Canada and most other countries outside the United States. Some military aviation fuel specifications require other conductivity limits at the point of use. Canadian civil specifications for Jet A-1 permit a maximum of 600 pS/m. In aviation gasoline specifications, additive use is optional and may be advised for very cold climates where reduced vapor pressure can give a flammable air-vapor mixture in containers or fuel tanks.

8.3.2 The minimum conductivity limits for aviation turbine fuels ensure adequate charge dissipation when filter separators or water-absorbing media monitors are used. The maximum limits prevent adverse effects on aircraft fuel capacitance gages.

8.3.3 Non-aviation fuels or other hydrocarbons are usually treated with additive to give a minimum conductivity of 50 pS/m at point and temperature of use. However, the national standards of Canada for diesel fuels (CAN/CGSB 3.6 and 3.517) incorporate a minimum of 25 pS/m for electrical conductivity at time, place, and temperature of delivery and are the only diesel fuel specifications worldwide to have a minimum conductivity specification requirement. This limit resulted from actual measurements of surface voltage, and so forth, made in fully instrumented trucks being loaded through filters. Effective Nov. 12, 2008, Specification D975 incorporates similar limits under most conditions. Conditions, especially temperature at the point of use and the method of fuel handling and distribution, must be carefully considered before a conductivity limit at the point of additive treatment can be established.

8.3.4 It is important to note that the conductivity of fuels containing additives can fall below 50 pS/m by mixing fuels containing additives with those not containing additives (commingling), or through additive loss in handling. It is therefore essential to monitor conductivity when a question exists of whether additive-containing or commingled fuels are being handled; if the resultant conductivity is less than the specified minimum, the fuel should be handled as if the fuel were unadditized.

8.3.4.1 In aircraft fueling systems, fuels containing conductivity improver additive but with a conductivity less than 50 pS/m should be treated as if the fuel was unadditized. Such fuel is no safer or less unsafe than unadditized fuels (**10**). (**Warning—**Residence time in the hose between the fueling facility and the aircraft manifold necessary for relaxation of static charge can become critical if filter separators are replaced by water-absorbing media monitors, although in a well-designed installation, the system should provide a safe situation by maintaining an adequate opportunity for electrostatic charge relaxation. Static discharges may occur in aircraft tanks if residence time is very short (**13**).)

8.4 *Addition of Conductivity Improver Additives:*

8.4.1 The most assured means of treatment is to add conductivity improver additive to finished product tankage at the refinery or depot. Conductivity measurement can then be part of a routine quality management system before delivery of the product to various means of transportation, and there is maximum opportunity to find and correct treatment errors.

8.4.2 The addition of conductivity improver additive is best accomplished by continuous injection into the inlet lines to bulk storage tanks. Additive may also be added directly to the tank but mixing is then required to physically distribute the additive throughout the hydrocarbon. Recirculation is satisfactory or mixing can be accomplished by addition of additive to a partly filled tank then completing the fill operation. Mechanical mixing is another method, but housekeeping is critical as tank bottoms may be stirred up. Additive may be added to a standing tank. A sun-heated tank will be mixed in several days by convection currents—in this case, it is important that the additive is diluted with the fuel before addition to assist its dissolution.

8.4.3 Another means of adding the additive is to inject at the loading rack just before flow into truck compartments, while ensuring that the injection system provides reasonably uniform treatment of the flowing product. However, the injection system must be scrupulously monitored to ensure it is operational at all times. This can be accomplished by using in-line conductivity monitors described in Test Method D2624, or other fail-safe techniques.

8.5 *Conductivity Changes:*

8.5.1 Fuel conductivity can be affected by temperature, handling, other additives, commingling with other fuels, and trace impurities that may not affect other properties. While sometimes unpredictable, these effects can be managed if allowed for during initial conductivity improver treatment.

8.5.2 Fuel temperature affects conductivity because viscosity change affects the rate at which charge can be conducted through fuel. The temperature-conductivity relationship **(14)** is roughly defined by the following equation:

$$\text{Log } k \text{ at } t_1 = n(t_1 - t_2) + \log k \text{ at } t_2 \quad (1)$$

where:

k = conductivity,

n = temperature/conductivity coefficient determined experimentally for the fuel, °C or °F, and

t_1 and t_2 = temperatures in the same temperature units.

Further discussion of low temperature effects is in Appendix X2 of Test Method D2624.

8.5.3 Loss of fuel conductivity during distribution and handling may occur due to adsorption of additives by surfaces such as pipelines, clay treaters or filter elements.

8.5.4 The conductivity-improving performance may be strongly affected by other additives and by trace materials in the fuel. These effects can be evaluated by treating representative samples containing other normally used additives. Other additives and trace materials can also cause loss of conductivity during storage in addition to initial effects following treatment. Some effects of other additives are known; others can only be determined by evaluation in the specific fuel.

8.5.5 Having evaluated these effects for the fuel and knowing the probable distribution effects, fuels are normally treated with a margin above the specification minimum. Thus aviation turbine fuels are normally treated to give an initial conductivity of about 150 to 250 pS/m.

8.5.6 A test method is being developed to determine the concentration of some conductivity additives in fuels.

8.6 *Effects on Other Properties*—Other usually measured properties of non-aviation fuels are not affected by conductivity improver additives at normal use concentrations. For aviation fuels, the water separation properties as measured by Test Method D3948 are affected. The magnitude of the effect depends upon other additives and also trace impurities and is not always predictable. This can be especially troublesome for fuels requiring high concentrations of conductivity improver additives. In cases where conductivity loss is a problem, addition of conductivity improver additive close to the time and place of delivery is frequently practiced.

9. Reports of Electrostatic Ignitions

9.1 The mechanisms for electrostatic ignitions in petroleum fuel systems can be very different. The amount and type of information reported is critical for the proper analysis of an ignition. In all cases, a brief description of the ignition is required and should strive to include the following minimum information:

9.1.1 Location and date,

9.1.2 Damage and injuries,

9.1.3 Weather conditions,

9.1.4 Types of petroleum product involved,

9.1.5 Nature of operation (truck loading, filling filter vessel, sampling, or gaging),

9.1.6 Possible sources of flammable atmosphere (low flash point, switch loading, mists, or sprays),

9.1.7 Possible sources of accumulating charge (low conductivity fuel, insulated conductors),

9.1.8 Possible sources of charge generation (flow rates, filtration in place, amount of relaxation time),

9.1.9 Method of liquid entry into vessel (top or bottom loading, nature of pipe end), and

9.1.10 Involvement of bonding or grounding.

9.2 The American Petroleum Institute (API) maintains a file on electrostatic ignitions. They have developed a questionnaire to yield a uniform report of conditions existing at the time of an ignition. This questionnaire is published as Appendix C of Ref (**1**) or may be obtained directly from API. This information permits an analysis of the conditions leading to electrostatic ignitions.

9.3 ASTM Subcommittee D02.J0 on Aviation Fuels has direct responsibility for this guide. Reports on electrostatic ignitions are called for and reviewed at all D02.J0.04 meetings. Electrostatic ignitions involving any petroleum product may be reported to D02.J0.04. This information provides learning and may lead to revisions of this guide.

10. Keywords

10.1 aviation fuels; distillate fuels; electrical conductivity; electrostatic charging; electrostatic hazards; loading; safety; sparking; static electricity

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