Designation: ~~D4865 – 19~~ D4865 – 23

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

This standard is issued under the fixed designation D4865; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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 stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

---

[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.J0.04 on Additives and Electrical Properties.

Current edition approved ~~July 1, 2019~~Nov. 1, 2023. Published ~~July 2019~~November 2023. Originally approved in 1988. Last previous edition approved in ~~2014~~2019 as ~~D4865 – 09 (2014).~~D4865 – 19. DOI: ~~10.1520/D4865-19.~~10.1520/D4865-23.

***A Summary of Changes section appears at the end of this standard**

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
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
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
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 and Liquid Fuels (Mini Method)
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 3.517 Diesel fuel
CAN/CGSB 3.520 Diesel fuel containing low levels of biodiesel (B1–B5)

2.4 *British Standards Institute (BSI) Standard:*
BS 5958 (Part 2) Recommendations for Particular Industrial Situations[5]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this guide, refer to Terminology D4175.

3.2 *Definitions of Terms Specific to This Standard:*

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

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

3.2.3 *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.

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

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

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

---

[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.

[3] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

[4] Available from Canadian General Standards Board (CGSB), 11 Laurier St., Phase III, Place du Portage, Gatineau, Quebec K1A 0S5, Canada, http://www.tpsgc-pwgsc.gc.ca/ongc-cgsb.

[5] Part 2 of British Standard Code of Practice for Control of Undesirable Static Electricity, available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.

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

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

3.2.7.1 *Discussion—*
Conductivity has also been expressed in conductivity units (C.U.) where I.C.U. = 1 pS/m = $1 \times 10^{-12}\ \Omega^{-1}\ m^{-1}$.

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

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

3.2.9 *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).

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

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

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

3.2.12 *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**).

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

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

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

3.2.16 *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.

3.2.17 *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.

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

3.2.18.1 *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.

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

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

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

3.2.21.1 *Discussion—*

---

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

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 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 from 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 from 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 m⁄s 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 s to 7 s after a system containing water absorbing media monitors and 5 s 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