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FINAL REPORT NO. 60653

STATIC ELECTRICITY RESEARCH PROJECT

SCE NO. 8984

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EXECUTIVE SUMMARY

Safety Consulting Engineers, Inc. received a request from the API committee on Safety and Fire Protection to conduct a research project on static electricity ignition hazards related to the petroleum industry.

The purpose of the research project was to:

- (a) Analyze technical data and information contained in the API RP 2003 and substantiate static electricity practices made therein.
- (b) Compare API RP 2003 with standards/practices on static electricity written by other associations.
- (c) Identify electrostatic ignition hazards in the petroleum industry not covered by API RP 2003.
- (d) Identify areas that require further research.

A very detailed and exhaustive literature search was performed. Over 200 publications on electrostatics in Safety Consulting Engineers' library were reviewed to determine which references needed to be collected. Literature was also searched for in books, journals, symposia, other standards, codes, regulations including governing bodies and associations in England and Germany. Information collected was used to substantiate recommendations in API RP 2003. A comparison is made in tabular form of what is in API RP 2003 and how it is substantiated by the literature.

Recommendations made in API RP 2003 were also compared with recommendations and standards of other organizations within the context of the petroleum industry. Comparisons were made for

completeness in practice. There is good agreement between API RP 2003 with other standards, however, there are differences and further research is necessary.

Literature was also reviewed for sources of information on current uses of plastics in the petroleum industry. Key people in the petroleum industry were contacted to determine the uses of plastics in the industry. Some of the general concerns were in the use of underground plastic tanks at service stations and if it was acceptable to use nonconductive vacuum hoses during tank filling operations.

Some of the conclusions drawn during this research project are:

- For liquids of very low conductivity (less than 2 pS/m) the 30 second residence time downstream of a filter is not very conservative. It should be increased to 100 seconds. This has been proved theoretically and is verified in published work.
- Plastic containers and equipment are responsible for many fires and injuries. Incidents of tank explosion have occurred during the splash filling of conductive liquids. Plastic tubing and small sample bottles have also contributed to fires in the handling of conductive liquids. Further research is needed in the use of plastic in the petroleum industry.
- Personnel grounding is a direct or indirect cause of hose fires during filling of tanks with flammable gas mixtures in most easily ignitable concentrations. Clothing is usually not a problem unless it is removed causing crackling discharges. Further research is recommended.

Standards need to be developed for the safe use of plastics in the petroleum industry. Certain areas of API RP 2003 require additional coverage including the use of plastics, static generation on clothing and surfaces, fiberglass storage tanks and

effect of various coatings on tank surfaces. The following are some of the areas where further research is recommended:

- Determine whether inner nonconductive sleeves in pipes and hoses are a brush discharge hazard during hose drainage and whether antistatic hose lines are needed in nonconductive liquid service.
- Theoretical and experimental studies on the effects of nonconductive and semiconductive lines and excess charge at free liquid surface and the possibility of propagating brush discharges.
- To determine if it is safe to use filters when filling conductive and semiconductive liquids into lined tanks and drums.
- Conduct a full scale experiment on a tank truck filled with a high flash point mineral oil using a pipe or composite "rough bore" hose. The measure of streaming current would determine whether such hoses are contributors to fires.

I. INTRODUCTION

Safety Consulting Engineers, Inc. (SCE) has prepared this report for work on the Static Electricity Research Project which was administered by the American Petroleum Institute's Committee on Safety and Fire Protection (COSFP). This project was performed in three phases:

Phase I: The technical data and information contained in API RP 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents, March 1982, validated to substantiate the recommendations made therein.

NOTE: Since a new version of API 2003 has been released, some issues may not apply.

Phase II: Areas that are relevant to electrostatic ignition hazards in the petroleum industry but are not covered, or are inadequately covered in the existing version of API RP 2008, were identified and documentation was provided where it exists for these areas.

Phase III: Areas from Phase I or Phase II that require further research were identified and research programs for these areas are proposed.

A. Background

Phase I

Recommendations stated in API RP 2003 are guidelines followed in the petroleum industry for protection from electrical ignition of flammable vapors due to static, lightning and stray currents. API RP 2003 is based on research and many years of practical experience in the industry. Some substantiation of the recommendations given in API RP 2003 has already been documented through COSFP's Technical Data Recovery Project and other technical

literature. However, many items may require further research to substantiate, such as the use of plastics and other nonconductive equipment.

Phase II

Certain areas of API RP 2003 may require additional coverage, including the use of plastics, static generation on clothing and surfaces, fiberglass storage tanks, and effects of various coatings. Static charges are generated during the flow of fluids and can be a concern with low conductivity fluids that may come in contact with flammable vapor/air mixtures. While earthing is the primary means of protection from incendiary discharge for systems with metallic conductors, it is ineffective when nonconductive plastic pipes, storage containers, sheets, coatings, liners, and clothing are used. Plastics are readily charged by contact electrification and induction and can dissipate charges very slowly, depending on resistivity, thereby producing hazards from discharges from their surface or from nearby insulated conductors. Therefore, standard criteria needs to be developed for the safe use of plastics in the presence of flammable atmospheres.

Phase III

For issues and recommendations contained in the current edition of API RP 2003 or identified in Phase II of this project that were not able to be validated or resolved, additional research was identified and programs were recommended for development and implementation were needed.

II. SCOPE OF WORK

A. Phase I

1. Objectives

The objective of Phase I of this research project is as follows:

- a. To substantiate the static electricity recommended practices outlined in API RP 2003 using internal API documents and any technical information from published sources.
- b. To compare API RP 2003 with static electricity practices written by other associations and governing bodies and identify areas of differences and provide substantiation of these differences.

III TASK PLAN

(A) Literature Search

The literature was searched for books, journals, papers, symposia, and task force reports containing information useful in substantiating the recommendations made in API RP 2003. This search included other standards, practices, guidelines, regulations, codes, and methods published by other associations and governing bodies.

Applicable documents from API, including those from COSFP's Technical Data Recovery Project were reviewed.

A computer search was performed at Safety Consulting Engineers, Inc. (SCE) using NTIS, Chemical Abstracts, Physical Abstracts, and Iquest Literature Service.

A quick review of all materials collected, including the over 200 publications on electrostatics in Safety Consulting Engineers' library and the libraries of Laurence Britton were performed to determine which references need to be collected from

libraries or publishers.

The following libraries were utilized to find the needed publications: The John Crerar Library, Northwestern University Engineering and Science Library, Illinois Institute of Technology Technical Library, Purdue University, University of Minnesota and the Wisconsin Physics, Chemistry and Engineering Libraries.

Governing bodies and associations, in England and West Germany were contacted to obtain codes, standards and regulations used in control of static electricity, lightning and stray currents.

A summary of all literature reviewed is found in Appendix D. Monograph.

(B) Literature Comparison

Experimental data, mathematical models, and scientific calculations were used to substantiate the recommendations in API RP 2008. Substantiation was as exhaustive as possible, within the constraints of the literature search performed in Part A.

As each section of API RP 2003 was reviewed, documents were analyzed as to how reliable the information is and how the information pertains to the recommendations of API RP 2003. A summary worksheet was prepared which briefly described what is in API RP 2003 and how it is (or is not) substantiated by the literature. The results are shown in Appendix A.

(C) Standards Comparison

The recommendations made in API RP 2003 were compared with recommendations and standards of other organizations within

the context of petroleum operations. The comparisons were made with regards to completeness and any conservatism present in the recommendations of API RP 2003. Differences in the practices were identified and substantiation of these differences was made wherever possible using the results of Part B.

Each section of API RP 2003 was compared to other standards using the information for substantiation from Parts A and B.

As each section was compared, a summary worksheet was prepared showing briefly what the differences in the standards are and how the differences can be resolved using the literature.

The National Fire Protection Agency recommended practices on handling and processing of flammable liquids (NFPA 30), control of static electricity (NFPA 77), and protection from lightning (NFPA 78) were compared to API RP 2003. Codes from the British Standards Institute ("Code of Practice for Control of Undesirable Static Electricity", BS5958), and the "Chemistry" Committee of the Chief Federation of the Industrial Trade Associations Center for Accident Prevention and Industrial Medicine from West Germany) ("Guidelines for Avoiding Danger of Ignition As a Result of Electrostatic Charges") were also compared. Other codes and standards include Chapter 7 on "Static Electricity" in the Army Safety Manual DARCOM-R 385-100, and National Safety Council Data Sheet 547. The standards comparison results are shown in Appendix B.

(D) Monograph

A monograph was prepared documenting the substantiations of API RP 2008 made in Task B and the comparisons made in Task C. The monograph was written in practical, tutorial terms for use by engineers and engineering managers in the petroleum industry. The monograph follows the order of subjects in API RP 2003 and a bibliography of material for further reference which was developed using the information management program. All substantiations and comparisons were traceable to the originating literature. Areas requiring further research were identified in the monograph. The monograph is found in Appendix D.

(E) Nonconductive Materials Study

(1) Objectives

The objectives of Phase II of this research project were as follows:

- a. To characterize the electrostatic hazards associated with the use of nonconductive plastics in the petroleum industry.
- b. To establish a well-supported methodology, with validations from existing literature, etc., of hazard identification which can be used by API committees in the development of relevant standards.
- c. To identify and provide validation for other areas recommended for expanded coverage in API RP 2003.

(2) Literature Search on Plastics

The literature was reviewed for sources of information on current uses of plastic in the petroleum industry and for information on current and past work done to identify and

quantify the hazards presented by their use.

(a) Literature Sources

A computer search was performed at SCE for information on the uses and hazards of plastics in the petroleum industry. In addition, the literature was searched to identify nonconductive materials use and safety around flammable liquids.

Governing bodies and associations were also contacted in order to obtain codes, standards, regulations and practices on static electricity control when using plastics with flammable liquids.

A summary of literature sources identified is shown in Appendix C.

(b) Field Uses/Experience

Key people in the petroleum industry were contacted to determine the uses of plastics in the industry and which of the uses should be covered in API RP 2003. A summary of industry contacts is shown in Table I.

(c) Standards Investigation Comparison

Currently accepted standards on the use of plastics were investigated to determine what criteria and recommendations are now being followed in other industries and how these apply to petroleum industry operations. The investigation included identification of the hazards involved, in reference to the methods used in other industries to eliminate them.

As each standard was analyzed, a summary worksheet was prepared which briefly showed what methods are used

TABLE I
SUMMARY OF INDUSTRY CONTACTS

COMPANY	SUBJECT	COMPANY PRACTICE
Conoco Oil	Use of Plastics	Sometimes are used They have many criteria to determine if non-metal material is to be used They do not use (FRP) plastic on truck Had one incident with a plastic tank awhile ago
ORYX ENERGY CO.	Use of Plastics	They use plastics and FRP tanks up to 80 gal size in exploration Not much in production they have a program to evaluate arcing during repair of PVC tube stock
Union Pacific Resource	Use of Plastic	They lost a salt water nonconducting tank to lightning They use small nonconducting containers for tank bottom material Also had underground tanks (Slop condensate) Tank hit by lightning
Unocal Calif	Use of Plastic Around Flammable Liquid	Nothing standard across company In oil and gas production, small (FRP and plastic) tanks (80 gal) used for additives and water Also use plastic (FRP) additive tanks by cooling towers They do not use portable plastic containers for flammable liquids

TABLE I (continued)
SUMMARY OF INDUSTRY CONTACTS

COMPANY	SUBJECT	COMPANY PRACTICE
Sun Refining Marketing	Use of Plastics	They use plastics at: - Refineries, for fire water - Sour H₂O stripper - Production 3" crude lines on production trucks (well to small truck) - Pipeline - crude oil 10-12" - Terminals - none used - Service stations - fiber glass/polyethylene tanks, unloading lines.
Amoco Oil Company	Use of Plastics by Flammable Liquids	Refining operations: - Use 55-gal poly drums max size - Repackages to smaller package Lubes packaged: in quart, gallon and 5 gallon of non-flammable liquids
B.P. America	Use of Plastics by Flammable Liquids	-
Chevron - Calf	Use of Plastics by Flammable Liquids	-
Exxon-Houston	Use of Plastics by Flammable Liquids	Referred to R. Murphy in New Jersey for response

TABLE I (continued)
SUMMARY OF INDUSTRY CONTACTS

COMPANY	SUBJECT	COMPANY PRACTICE
N.J.A. Petrochem Co.		Flammable liquids can be placed in containers up to 250 lengths: if temp. of liquid is less than 5°C below flash point and plastic has surface resistivity less than 10^{11}ohm or lining is less than 0.5 mm thick For nonconductive containers of surface resistivity $> 10^{11}$ohm (for liners < 0.5mm thick) all flammable liquids except CS₂ and alcohol can be placed in them if container is less than 5 liter size.

General Company Comments:

- Should vacuum truck hoses be conductive or OK to be nonconductive.
- Concerned about using plastic (FRP) tanks (underground at service stations.
- Concerned about use of braided metal or synthetic sleeve on liquid fill line.

in other industries to eliminate the hazards involved. The results of the standards comparison are shown in Table II.

IV CONCLUSIONS

While Figure 1 in API RP 2003 is a good approximation for fuels such as paraffinic mixtures with regular ASTM distillation curves, it is erroneous for many single component hydrocarbons and other flammables. A better illustration is recommended for these cases and Figure 1 should be accompanied by a use limitation statement including a caveat about mist and foam ignition. The ignition energy of mist below (about) 30 micron diameter converges with that of a vapor. Very fine mist can be produced during splash filling and as foam breaks up.

It should be noted that exponential relaxation (above 2 pS/m) is not governed solely by "rest conductivity" as measured in the laboratory. The effective conductivity in the field is significantly reduced by temperature decreases (for example from about 100 pS/m at 25°C to about 30 pS/m at -10°C). Further, highly charged liquid may display a relaxation time that is up to one order of magnitude greater than predicted (this effect is usually unimportant unless a microfilter or other source of high charging is present). To address the temperature problem, either the nominal "static accumulation" conductivity might be raised to 150 pS/m, or a temperature correction can be made. In addition, the conductivity can be measured at the temperature of interest.

The velocity-diameter limit developed experimentally for tank truck filling was developed for smooth-bore pipes and hoses during

TABLE II

**STANDARDS COMPARISON
INSULATING MATERIALS IN PRESENCE OF FLAMMABLE LIQUIDS**

STANDARD	DATE	SUBJECT	REQUIREMENT	COMMENTS
NFPA 77 Recommended Practice on Static Electricity	1983	Para 7-8 plastic and plastic lined containers Non- metallic containers to handle flammable liquids Para 9-8 container filling	5 - 55 gal sizes are potentially dangerous "4 - 8.5 container of glass or non- conducting materials of 5 gal or less usually are filled without precaution see para 7-8"	Hazards are not indenti- fied or cat- egorized This depends on the charging and drainoff character- istics of the liquid material combinations
DoD HDBK- 263 ESD Control Handbook	2 May 1980	Definitions of Materials	- <u>Insulative material</u> Surface resistivity >10¹⁴ohm/square - <u>Anti-static material</u> Surface resistivity >10⁹ to <10¹⁴ohm/square - <u>Static dissapa- tive material</u> >10⁵ to <10⁹ ohm/square - <u>Conductive material</u> >10⁵ohms/square	Good defini- tions

TABLE II (continued)

STANDARDS COMPARISONS
INSULATING MATERIALS IN PRESENCE OF FLAMMABLE LIQUIDS

STANDARD	DATE	SUBJECT	REQUIREMENT	COMMENTS
BS-5958 Proposed changes	1991	Storage tanks	4.2.1 Large storage tanks completely fabricated from highly resistive materials with volume resistivities greater than 10^8 ohm m or surface resistivity greater than 10^{10} ohm are not recommended for flammable liquids. <u>Exception</u> if liquid handling operations do not produce dangerous levels of static electricity and no charge generating process exists outside the tank.	Does not define dangerous levels of static electricity

TABLE II (continued)

STANDARDS COMPARISONS
INSULATING MATERIALS IN PRESENCE OF FLAMMABLE LIQUIDS

STANDARD	DATE	SUBJECT	REQUIREMENT	COMMENTS
BS-5958 Proposed changes	1991	Non-metallic storage tanks - underground	5.2.1 Tanks should be individually designed for each specific application. To conform to safety, max charge produced in filling of tank must not produce field strength to cause discharge.	Propagating brush discharges are a strong possibility here. Restrictions or ES charging and flowing should be better defined
			5.1 If liquid is conductive (>50 ps/m), charge will dissipate safely to earth when it is in contact with a conducting surface to ground	Immiscible liquids could compromise safety if flash point and ES charging is favorable
			9.2.2 If flammable atmospheres are possible near that vehicle tank, conductive or semi-conductive hoses should be used	Charging and flow rate also are important
			12.4.1 Highly resistive containers can be used for flammable liquids occasionally provided that the ES ignition risk is acceptable	Risk not defined

TABLE II (continued)

STANDARDS COMPARISONS
INSULATING MATERIALS IN PRESENCE OF FLAMMABLE LIQUIDS

STANDARD	DATE	SUBJECT	REQUIREMENT	COMMENT
			12.4.4. When low conductivity liquids are used, highly resistive containers up to 5 liters: are alright. Above that expert advise should be sought 12.5 In continuous flammable atmospheres highly resistive containers should not be used independent of size	This is questionable depending on liquid on mixture charging Good

overhead filling via a dip pipe. Products between 0.36 and 0.50 m^2/s are suggested in the literature, while higher values may be used for compartment lengths greater than 2 meters. For bottom connection filling the product should not exceed 0.36 m^2/s and the inlet should be fitted with a deflector to prevent jetting. The value of 0.5 m^2/s being used has been successful in loading typical petroleum fuel to date. Composite hoses containing an internal grounding spiral should be avoided when loading nonconductive flammables because of the excessive static generation apparently caused by the spiral, especially in hoses of small diameter. To allow for the limited test conditions under which the API velocity-diameter limit was developed (uniform charge distribution, no free water etc.), and some fires which have occurred at low product values, it should be stressed that a lower v·d product is desirable particularly for bad actors like toluene. An important point to make is that for equal values of v·d product, the maximum safe filling rate is proportional to filling pipe diameter. Where there is a choice, larger diameter pipes are intrinsically safer for a given flow rate. This is additionally important for rough bore (spiral wound) hoses where for smaller diameters the blockage ratio and charging should be greater. If rubber boots on similar devices are connected to the end of dip pipes they should be conductive and reach to the bottom of the tank, and be in contact on the bottom to avoid undue turbulence.

A potential problem with wound composite hoses is that the inner spiral is often not attached to the end connectors and in

some cases the gap is an effective spark source during draining of nonconductive liquid from the hose. To avoid this hazard, a semiconductive liner may be used. Alternatively, the hose can be designed to provide bonding via the inner spiral. To show that the inner spiral is bonded, one design uses an isolated outer spiral and other designs (such as an outer spiral bonded to a single, grounded end connector to avoid complete isolation) might be specified. Also the problem will not exist with adequate time to relax charges.

Section 2.4.2 in API RP 2003 states that nonconductive hose can be used provided the end connector is bonded. Use of nonconductive hose for nonconductive flammables can be hazardous since discharges may occur on the surface(s). At high levels of charging, such as downstream of a filter, powerful propagating brush discharges may occur. The meaning of the statement made that "continuity is not required in bottom or top loading through tight connections" is unclear. If tight means electrically contacting, the statement is correct.

Hoses (and pipe) containing a continuous nonconductive liner may undergo pinhole puncture on the lining by small propagating brush discharges when charged nonconducting liquid accumulates surface charge on the liner. This is most likely to occur downstream of filters. The problem has occurred in steel flexible hose with extruded thermoplastic liner, where repeated puncture at a point caused leakage. With composite hose containing a coated spiral any pinholes will go to this spiral rather than through the

carcass, since leaks should not be caused, the phenomenon probably has not been noticed. It is unknown whether these discharges could produce a hazard or not. This type of discharge can be avoided using a semiconductive liner (metal or carbon filled polyolefin) or any type of hose with internal bare metal surfaces such as an uncoated inner spiral.

In API RP 2003, Figure 7 shows what appears to be a close-coupled filter in drum filling and states that the hose can be nonconducting. Both can be extremely dangerous in some conditions for nonconductive flammables as is well supported by literature and by accident histories.

Purging recommendations should refer to NFPA 69 to generalize the coverage.

The 30 second residence time downstream of a filter is not conservative for liquids of very low conductivity (less than about 2 pS/m) and may have to be increased to 100 seconds. This is proved theoretically and is verified by published test work. The reason for this need is that filters generate high levels of charge even at low conductivity; even where this is not the case the charge density dependence of hyperbolic relaxation makes the time taken to relax to acceptable levels ($20\text{--}30\text{ }\mu\text{C}/\text{m}^3$) almost independent of the initial charge density above about $100\text{ }\mu\text{C}/\text{m}^3$. Temperature effects on conductivity should be considered to make 2 pS/m a meaningful demarcation. Note that the NFPA and BS guidelines calling for "3 relaxation times" residence would require 27 seconds for a typical hydrocarbon at 2 pS/m which is close to the "worst

case" 30 seconds presently given by API. However, below 2 pS/m further analysis is necessary to determine if 20 seconds is safe. Virtually in all cases, 100 seconds is safe.

While 50 pS/m is a useful demarcation for static accumulation in grounded equipment, it does not represent the conductivity level above which a liquid is "Conductive". This has been drawn at various levels according to the handling operation involved. A conservative "ceiling" level of 100,000 pS/m has been established. A "safe" conductivity for almost all operations, including those involving stirred slurries and pipes/hoses lined with high resistivity material has been established at 1,000 pS/m. Other levels (for example 200-300 pS/m) have been applied to certain military applications such as war planes.

Plastic containers and equipment are responsible for many fires and injuries and the present coverage is entirely inadequate. In the case of FRP and other plastic aboveground tanks, splash filling must not be done. There was a recent FRP tank explosion involving splash filling of a conductive liquid; conductive liquids give rise to surface sparks rather than brushes and only a few kV is needed to ignite vapor. It is important to stress that with plastic containers there is no safe liquid conductivity. Sparks from conductive liquids can be produced by splash filling or simply rubbing the outside of the container, which induces very high potentials in the liquid. A charged plastic surface can give rise to incendive brush discharges or may induce hazardous potentials on nearby conductors. Even plastic tubing and small sample bottles

(when handling conductive liquids) have contributed to causing fires.

In relationship to personnel grounding, there is some evidence that ungrounded personnel are a direct or indirect cause of hose fires following tanker filling in high risk situations. Personnel grounding may be required in high risk areas such as handling of liquids where flammable gas mixtures are in most easily ignitable concentrations. It is true that clothing is not usually a problem unless it is removed causing crackling discharges (brush types). The type of clothing can determine the charge on an ungrounded person, however. Personnel grounding may be achieved using a variety of commercially available devices (conductive/antistatic shoes, foot grounders, bracelets) and commercially available accessories such as conductive paint for floors, and resistance testers to ensure the devices are operating properly. In some situations, personnel grounding may be required to prevent fuel vapor ignitions.

To avoid stray currents in wharf lines an insulating flange (commercially available) should be installed. Nonconductive hose can be used providing no additional hazards can occur.

RF stray currents in the vicinity of radar and radio transmitters should be addressed. Shell has published a nomograph allowing ignition hazard field strength thresholds to be found for methane and hydrogen with respect to source frequency and the loop perimeter of any adventitious antenna.

V RECOMMENDATIONS FOR FURTHER WORK

- (1) A project is recommended in which an electrically isolated tank truck (or less desirable, a tank of similar dimensions) would be grounded through an electrometer and filled with a high flash point mineral oil with a conductivity of about 2 pS/m, either through a pipe or a composite "rough bore" hose. The measurement of streaming current would determine whether such hoses are a cause of mysterious fires. Simultaneously it would be possible to use an image intensifier to observe any electrostatic discharges in the truck. An unbaffled truck would simplify this. Grounded probes could be used to simulate truck internals. Both top and bottom filling might be carried out using image intensification to verify the BS 5958 recommendation to limit bottom fill flow rates to 25% those of top filling.
- (2) Research is recommended to determine whether inner nonconductive sleeves in pipes and hoses are a brush discharge hazard during hose drainage and whether antistatic hose liners (such as used by Willcox) are needed in nonconductive liquid service where spiral breakage is not present.
- (3) Plastic manually-operated drum pumps are frequently used to transfer flammable liquids and there has been a report of a fire originating inside a drum. It appeared possible in this case that a brush discharge occurred from the pump handle being operated at the time, although a discharge from the operator might alternatively have occurred. The liquid was conductive. No published information has been found on drum pump hazards and some study should be made.
- (4) Theoretical and experimental studies of the effects of nonconductive and semiconductive liners and excess charge at free liquid surfaces are needed. While it is unlikely that propagating brush discharges are produced on plastic liners in liquid handling systems, this possibility is considered by various authors.
- (5) Filters are being used on lances when handling conductive and semiconductive liquids. Research is needed into whether this practice is safe, particularly when filling lined tanks and drums. There would appear to be a problem during the early stages of filling especially.
- (6) In the Petrochemical Industry the use of lances is often limited by personnel exposure problems when handling toxic or malodorous liquids. Research is needed as to whether splash filling of lined drums is an acceptable

procedure and what the limitations (liquid conductivity, liner thickness and resistivity etc.) should be. In some cases the exposure problem can be mitigated by the use of spring-type discharge electrodes at the end of the lance, which uncoils into the liquid during flow, minimizing wetting of the lance itself. Such devices are relatively unheard of but may be purchased by special order.

- (7) There have been numerous studies of brush discharges from liquid surfaces but apparently none on the formation and effective energy of the "go devil", a surface discharge that can be several feet in length and which is somewhat analogous to the "wall-to-cone" (or "Bulking Brush") discharges seen during silo filling. By analogy one might expect the effective energy to be greater than for brush discharges, perhaps around 10mJ. Such discharge might be responsible for mist ignition of high flash-point liquids.
- (8) It is recommended that the industry hold discussions with container manufacturers to determine the feasibility of antistatic plastics for use in all-plastic drums and other applications. For example, conductive carbon black-loaded polyethylene may be directly bonded to an inner polyethylene drum shell allowing direct grounding while avoiding the mechanical problems of polysteel drums and retaining the advantages of a polyethylene liner. The conductive plastic will have a greater thermal conductivity than HDPE and may improve fire resistance by the Factory Mutual test. By improving the fire resistance with respect to steel drums the present restrictions on plastic drum storage might be eased. A groundable plastic drum would present no external discharge hazards and for conductive flammables could be safely loaded and unloaded using a metal dip pipe.
- (9) The effect of entrained water or electrostatic charging for nonconductive material contact by flammable liquids should be studied.
- (10) Detailed proposed studies will be supplied under separate cover.

APPENDIX A

SUMMARY OF LITERATURE SUPPORT FOR RP 2003

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.1	Resistances of less than 1 meg-ohm may act as short circuits.	No information.		
2.3.1- 2.3.3	Figure 1 shows relationship between temperature, vapor pressure, flammability limits of petroleum products.	Shows plot of Reid vapor pressure as a function of temperature for various fuels. Provides flammability limits. Experiments with the flow of hydrogen carbon solutions through SS tubing to measure charging current magnitude. Measurements obtained indicate that using liquid conductivity as the only parameter by which to assess charging phenomena is misleading. Shows sample of suggested plot for benzene vapor. Establish most easily ignitable vapor space mixtures from vapor pressure data, especially for "bad actors." Shows sample of suggested plot for hydrocarbon vapors Preliminary screening on basis of vapor pressures is misleading; use relationship between dielectric constant and conductivity to assess electrostatic hazard.	Strawson Ref. #12 16 Goodfellow & Graydon Ref. #71 1267-1280 Britton & Smith Ref. #1 54-55 Britton & Smith Ref. #2 201 Saletan Ref. #3 101 Saletan Ref. #4 101-102	Yes Not addressed Not addressed Not addressed Not addressed
2.4.1	Bond resistance as high as 1 meg-ohm is adequate for static dissipation	Discusses bond resistance values offered by various agencies. Resistance to earth should be less than 10 ohms for practical convenience.	Mancini Ref. #5 27-28 Loveland Ref. #27 5	Yes and No No

SUMMARY OF LITERATURE SUPPORT FOR RP 2003

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.4.1	(continued) Bond wire connection is essential where high- and intermediate- vapor- pressure products are loaded through top domes. Closed connections cannot yield sparks irrespective of whether conducting or nonconducting hose is used.	Summarizes earthing & bonding criteria in various zones. See Table 1. Resistance of no greater than 1 meg-ohm under even unfavorable conditions; when capacitance is less than 100 pF, resistances of up to 10⁸ ohms are sufficient using RC=10 ms; see Case Study 2 Bond fill pipe to tank. Resistance through tires must be low enough that dangerous voltages (1500 volts or more) will not build up in system if truck is not grounded. Discusses laboratory study done on small van. Experiments involving the measurement of voltage buildup on rubber tires. Discusses non-static tires. Investigates effect of insulated ball valve on flow of toluene/water mixtures in metal pipeline. Electrification increases markedly at constrictions when there is free water present in fluid. Discusses isolated conductors. Provides example of insulated fittings in GRP tanks. Details of experiment involving insulated fittings in GRP tanks.	Gibson & Harper Ref. #11 35-37 Haase Ref. #8 60-61, 66, 71 Mancini Ref. #5 28-29 Bulgin Ref. #46 583-587 Gibson & Lloyd Ref. #69 339-349 Gibson & Harper Ref. #11 33-35 Tinson Ref. #7 309	In some cases Yes and No Yes No No No No

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.4.1	(continued) Asphalt and crude oils do not have static accumulating capabilities.	Details of accident case involving leading flange connection. Conducted ignition experiments with diesel oil in insulated container. Found there was incendivity to local vapors and oil mist. Also provides theoretical approach.	Luttgens Ref. #7 250-251 Britton & Williams Ref. #2 185-206	No Needs clarification.
2.4.2	Bond wires not needed around flexible, swivel, or sliding joints. Electrical continuity in fill pipe assembly not needed for closed system loading, and bottom or top loading through tight connections.	No information No information.		
2.4.3	In past, maximum loading velocity restricted to 15-20 ft/s in tank truck filling. Bulk loading is better criterion than linear velocity for determining electrostatic accumulation. Use a vd value of 0.5 maximum for tank trucks: restrict linear flow velocity to 7 m/s maximum.	No information Discusses variables affecting charge on fuel. Discusses new theoretical and experimental studies regarding electrification during tank filling of hydrocarbons.	Leonard Ref. #14 17-27 Macksimov Ref. #10 137-142	No

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.4.3	(continued)	Discusses experimental study performed to determine typical sparking conditions in road tankers. Review studies done by other workers and discusses pros and cons of currently accepted velocity restrictions. Offers recommendations. Details experiments: proposes velocity restrictions based on these experiments. Laboratory and full-scale tests on the loading of iso-octane and jet fuel after passage through a filter. Develops charge relaxation theory.	Rees Ref. #15 13-25 Strawson & Lyle Ref. #20 26-30 Bustin Ref. #30 209-216	Yes and No Yes No
2.4.4	Splash loading may contribute to electrostatic charge generation; during top loading of tank.	Discusses studies concerning drop tube loading of tank trucks and effect of antistatic additives on fuel electrification. Conducted full scale experiments on loading of kerosene into a metal tank. Observed level of sparking in presence of propane air mixture purposely introduced into tank. Survey of studies done by various workers regarding tank truck loading. Briefly presents workers' conclusions. Review of experiments on tank truck loading with low conductivity fuel.	Mahley Ref. #36 53-55 Kramer Ref. #19 361-371 Leonard Ref. #14 17-22 Lyle & Strawson Ref. #35 455	Yes Yes Yes Yes

SUMMARY OF LITERATURE SUPPORT
FOR RP 2003

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.4.4	(continued)	Details of experiments on simulated filling of tank truck with gasolines from different companies. Measured magnitude of charges. Performed experiments to simulate sparking during loading of road tankers. Developed mathematical model of same and compared to experimental results. Offers recommendations for safe filling rates. Tests conducted at full-scale fueling test facility to study flow rate, splash loading, temperature, filtration, drop tube vs. bottom loading, and conductivity additives. Additives are recommended as only viable means of static control. Tests conducted at full-scale refueling facility to measure charge density on diesel fuel. Provides theoretical treatment of subject. Discusses additives. Full-scale experiments that simulate refueler loading. Studied effects of drop tube design, linear velocity, compartment size, fill pipe height, fuel conductivity, wet fuel & filtration. Experiments with drop tube height; photographs of sparks & turbulence.	MacKeown & Wouk Ref #35 455 Strawson & Lyle Ref. #48 276-287 Warren Ref. #50 111-122 Bright Ref. #17 132-139 Mahley & Warren Ref. #58 116-120 Lyle & Strawson Ref. #16 234-247	Yes Yes Yes Yes Yes Yes

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.4.4 (continued)	If fill pipe does not reach tank bottom, restrict flow velocity to 1 m/s until outlet is submerged.	Keep flow rate down until filling pipe is covered. Critical stage is before fill pipe is submerged; pump at initial rate of 1 m/s.	Tinson Ref. #6 310 Bright Ref. #17 138-139	Yes Yes
2.4.5	Bottom loading of tank trucks reduces electrostatic hazards that may arise from improper bonding and positioning of fill pipe Bottom loading produces higher liquid surface voltages than fill pipe loading.	Full-scale experiments on bottom loading of tank refueler with jet fuel. Variables studied were hose diameter & length, & effectiveness of relaxation chamber. Surface potentials obtained in this study are smaller than for top-loading studies. Flow velocity should be well below 30 ft/sec. No information.	Leonard & Carhart Ref. #61	Yes
2.4.6	History of accidents in unbaffled tank trucks during highway transport due to static generated by splashing of liquid.	Static electricity caused by splashing truck swaying, and rapid movement of truck.	Guest Ref. #18 69	Yes and No
2.4.7	Do not lower conductive objects into tank truck compartment during or immediately after filling; one minute waiting period is sufficient to relax charge.	No information.		
2.5.1	Resistance of rail tank cars to ground through rails is low enough to prevent electrostatic accumulations bonding of tank car or rails to fill pipe is unnecessary.	No information.		

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.5.3	For products loaded into railcars with conductivities less than 50 pS/m, restrict vd value to 0.8 and loading velocity to 7 m/s maximum.	Discusses new theoretical and experimental studies regarding electrification during tank filling with hydrocarbons. Conducted full scale experiments on loading of kerosene into a metal tank. Observed level of sparking in presence of propane-air mixture purposely introduced into tank. Experiments with drop tube height. Photographs of sparks and turbulence. Tests conducted at full-scale refueling facility to measure charge density on diesel fuel. Provides theoretical treatment of subject. Discusses additives. Performed experiments to simulate loading of rail tank cars. Developed mathematical model of same and compared experimental results. Offers recommendations for safe filling rates.	Maksimov Ref. #10 137-142 Kramer Ref. #19 361-371 Lyle & Strawson Ref. #16 234-247 Bright Ref. #17 132-139 Strawson & Lyle Ref. #48 276-287	No. Derived a relationship to determine the permissible filling rate based on conductivity, filling pipe size and tank configuration. Yes Yes and No No No. Conducted experiments and developed mathematical model to predict safe filling rates based on type of fluid, pipe diameter and geometry of tank.

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.5.3	(continued)	Full-scale experiments that simulate refueler loading. Studied effects of drop-tube design, linear velocity, compartment size, fill pipe height, fuel conductivity, wet fuel and filtration. Provides details of experiments & reasoning for the given equations.	Mahley & Warren Ref. #58 116-120 Stawson & Lyle Ref. #20 26-30	Yes and No Yes
2.5.4	Unloading procedures of any type for rail tank cars need no protective bonding.	No information.		
2.6	Metal drums and cans being filled from other containers while both rest on conductive foundations need no further bonding as long as the fill nozzle remains in contact at metallic spout.	Presents details of experiments simulating worst case scenario for unlined drum filling. Also presents theoretical models.	Britton & Smith Ref. #21 65-72	Yes
2.7	Bonding or grounding of cars while being filled at gas station is unnecessary. Bonding between tank trucks and underground gas stations tanks is unnecessary, provided that hose nozzle remains in metallic contact with tank fill pipe or is tightly connected.	Conducted experiments; sample calculation showing hypothetical case; need more than 100,000 megohms in tires to charge car. Details of experiment; total charge produced in this case showed up to be much less than filling truck at the filling rack.	MacKeown & Wouk Ref. #22 661-664 MacKeown & Wouk Ref. #22 661, 663	Yes Yes
2.8	Protection against electrostatic discharge is achieved for filling marine craft if fueling nozzle is kept in metallic contact with fuel tank fill pipe.			Yes and No

SUMMARY OF LITERATURE SUPPORT FOR RP 2003

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.9	Regarding aircraft fueling: a) Bond fuel hose nozzle to plane by means of short bond wire and clip.	Survey of studies done by various workers regarding aircraft fueling. Briefly presents workers' conclusions. Conducted laboratory scale experiments involving filter & tank arrangement for circulation of fuel. Simulation of spark discharges during aircraft fueling. Review of studies on aircraft fueling. Presents simulated aircraft fueling experiments to show how fuel conductivity varies during loading procedure. Laboratory and full-scale tests on the loading of jet fuel after passage through a filter. Develops charge relaxation theory. Developed theoretical model of rectangular metal tank partially filled with charged liquid. Calculated ES potential, field and energy. Compared results to actual aircraft fueling experiments. Found reasonable agreement between calculated and experimental values.	Leonard Ref. #14 17-22 Leonard Ref. #42 100-111 Lyle & Strawson Ref. #35 455 Foster Ref. #44 78-88 Bustin Ref. #30 209-216 Carruthers & Wighley Ref. #77 180-195	RP 2003 does not address aircraft fueling in much detail. Same Same Same Same Same

SUMMARY OF LITERATURE SUPPORT FOR RP 2003

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.9	(continued) b) If small planes are fueled by gas station type hose (up to 25 gal/min), bonding is not necessary. c) Some laws require plane, fueler, and hydrant vehicle to be interconnected by bond wires to low resistance ground (less than 10,000 ohms). d) No bonding required when fueling aircraft through a tight metal-to-metal connection.	Bond nozzle to aircraft to avoid unknown or unanticipated problems; other bonding is designed to control external sparks which have a low probability of occurring. No universal consensus otherwise. Requires further investigation. No information. Simulated large-scale experiments of fueling justify potential hazards and the need for investigating means of static control. Simulates experiments with aircraft hoses; verifies external bonding wire clip arrangement as best.	Mancini Ref. #5 29 Bruinzeel Ref. #24 125-139 Carruthers Ref. #25 176-177	Yes and No No Yes
2.10	Regarding tank ship/barge loading: a) Limit velocity of incoming liquid to 1 m/s until inlet opening is submerged from 0.3 to 2 meters.	Discusses conclusions drawn from early study done on tanker loading. Review of work on ship tank loading related to liquid charge density.	Mahley Ref. #36 55 Lyle & Strawson Ref. #35 454	No No, Theoretical & experimental measurements of charge density in ship tank loading. No generalization & results.

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.10	(continued) b) Use inert gas blanketing or conductive additives as an alternative. c) No bonding required because hull of ship is in contact with water and is inherently grounded.	Computer modeling of ignition hazards arising during the loading of tankers with hydrocarbon products. Focuses on sparks arising from fixed-in-place tank washing equipment. Suggests spark-relieving techniques. Inert gas is often effective in fuel handling but costly and difficult to maintain. Details accident case involving the loading of kerosene into a steel barge. Bonding serves no useful purpose in any kind of water, even if the hull is painted or covered with marine growth.	Butterworth & Brown Ref. #47 9-26 Smith Ref. #59 64 Beach Ref. #9 85-86 Mancini Ref #5 29	No. Published experimental results on electrostatic conditions in tank washing machine. Yes and No No Yes
2.11	Regarding metal storage tanks: a) Static generating and static-dissipating qualities of stored liquid determine possibility of sparking. b) Avoid splash filling; outlet of fill pipe should discharge near bottom with minimum agitation.	Accident case history involving the filling of a tank with liquid diphenyl. A layer of solid diphenyl subsequently formed on inside surface of vessel, preventing dissipation of charge. Discusses example of acid transfer by compressed air into tank. Provides calculations. Details of accident case involving insulated rubber sleeve on metal funnel used to fill metal storage tank.	Luttgens Ref. #7 251-253 Saletan Ref. #4 104-105 Loveland Ref. #27 5	Yes Yes Bonding is not addressed for storage tanks.

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.11	(continued) c) Limit velocity of incoming liquid to 1 m/s until outlet is well submerged. d) In the case of a floating-roof tank, follow above precautions until roof becomes buoyant; no precautions necessary after this because of the absence of a flammable vapor space. e) Some types of nonconducting floating-roof tank covers have isolated metallic clips which require bonding.	Review of work on large storage tank. Conducted experimental studies to determine safe filling rates after rail and food tank cars. Discusses experimental study involving the use of floating blankets of different designs. No information.	Lyle & Strawson Ref. #35 455 Stawson Ref. #12 16 Mahey Ref. #36 52	Yes No The topic of floating blankets on liquid surface of cone roof tanks is not addressed.
2.12	Regarding air-blown agitators: a) Causes prolific electrostatic discharge. b) Protect agitator vessel by inert-gas blanketing or by continuous treating system.	No information. No information.		
2.13	Regarding blending tanks and mixers: a) In-tank jet mixing and high velocity propeller mixing stir up settled water and generate electrostatic charge.	Details of recurring accident cases involving the blending of silicone products. Details of experiments involving measurements of charge density during mixing in a small vessel with nonconductive solvents.	Beach Ref. #9 86-87 Owens Ref. #34 734-748	Yes Yes

SUMMARY OF LITERATURE SUPPORT FOR RP 2003

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.13	(continued) b) Floating roof tanks are desirable for blending or if necessary, use gas blanketing.	Discusses mixing vessels and their hazards. Provides accident case histories and safety recommendations. For high energy mixing & blending operations, a "safe figure" of about 1000 pS/m has been suggested. Inert atmosphere is often effective in fuel handling but costly and difficult to maintain.	Owens Ref. #56 1428-1429 Loveland Ref. #27 9 Smith Ref. #59 64	Yes No Yes and No
2.14	Coating of paint, plastic, or aluminum oxide on inside of cargo or storage tank does not present electrostatic hazard.	Gives details of ignition experiments performed on plastic sheets and plastic coated metal surfaces. Presents theoretical and experimental discussion of lined drums. Measurements of electrostatic charging capacity of various films and coatings with different thicknesses. Thin porous coatings do not cause brush discharges but nonporous thin coatings can.	Heidelberg Ref. #37 147-155 Britton & Smith Ref. #21 70, 72, 77-78 Maurer Ref. #85 217-222	Yes, although RP 2003 does not discuss coating thickness. Yes Yes
2.15	Regarding sampling, gauging, high level devices: a) Use natural fiber ropes, not synthetic ropes. b) Wait 30 minutes after filling large storage or ships' tank before hand gauging or sampling.	No information. No information.		

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.15 (continued)	c) In tank trucks, rail cars or smaller volume vessels, wait 1 minute more before gauging or sampling. d) Completely nonconductive hand gauging or sampling devices require no waiting period. e) Bond floats of automatic gauging devices to vessel shell through lead-in tapes and/or guide wires. f) Fires caused by static electricity during LP-gas sampling rarely occur; fires confined to open sample containers. g) Open metal graduates used for sampling must be bonded to fill pipe. h) If graduate is nonconducting or if a closed container sampling procedure is used, bonding or grounding is not useful. i) Alarms or detectors used in the presence of flammable vapor-air mixtures should be made of nonconductive material or be properly bonded.	Experiments on initiation of sparking with metal electrodes lowered to kerosene surface after flow of kerosene through a filter to a large tank. No information. No information. No information. No information. No information. No information.	Johnson Ref. #70 53-65	Yes
2.16	Regarding abrasive blasting: a) Sparks have been observed jumping from rubber hose to grounded objects during grit blasting.	Experiments on solid particles issuing as a jet through an orifice. Nature of charge acquired is investigated.	Banerji Ref. #53 428-431	Yes

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.16 (continued)	b) Special hoses with built-in metallic shielding to prevent sparking are available from vendors. c) Within stream pattern no flammable concentration likely to exist because of sweeping action of air stream.	No information. No information.		
2.17	Regarding purging & cleaning of tanks and vessels: a) Steam jets generate prolific charge on nozzle and insulated objects on which the steam impinges.	Discusses 1969 tanker explosions that occurred during washing. Details experiments involving the measurement of static charge and field strength produced by steam jets and water atomizer. Brief discussion on previous work regarding water jets. Discusses common situation of tank cleaning with an organic solvent flowing through spray nozzle. Provides calculations. Discussion of charge generation during tank washing.	Mahley Ref. #36 55-57 Napier Ref. #39 244-265 Klinkenberg Ref. #29 65-66 Saletan Ref. #4 103-104 Van Der Meer Ref. #49 153-156	Yes Yes Yes Yes Yes

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.17	(continued)	Experiments on full-scale tanks to simulate charged mist generation during tank washing. Insulated objects inside tank were charged rapidly and ignitable sparks were observed. Experiments on liquid sprays, liquid jets and gas jets. Discussion on how charge develops in each of these situations. Laboratory-scale tests to simulate tank washing operations. Emphasis on earthed protrusions in a charged water aerosol and the presence of isolated slugs of water. Laboratory-scale experiments on charges produced on mists by jets. Current generation dependent on jet velocity and liquid conductivity. Laboratory-scale experiments of test effect of organic additives and strong electrolytes on charging of water mist. Seawater-crude oil mixtures also tested. Level of charge depends on type and concentration of solute and water-oil ratio.	Van Der Weerd Ref. #50 158-177 Banerji Ref. #53 409-428, 431-433 Hughes Ref. #60 966-971 Vos Ref. #65 184-192 Vos Ref. #66 165-171	Yes Yes Yes Yes Yes

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.17	(continued)	Full-scale tests on tanks equipped to produce charged mists. Spark mechanism associated with water slugs. Ignition tests associated with protruding objects inside tank. Theoretical approach to charge generation during tank washing. Four different geometric configurations developed. Experiments on spraying of kerosene-water mixtures. Charge density markedly increased in the presence of free water. See Figure 7. Brief discussion on electrification of drops and sprays. Sample calculation. Computer modeling of tank washing operations and associated ignition hazards. Focuses on isolated slugs of wash water. Computer studies on isolated slugs of wash water and on sloshing of liquid contents as pertains to ESD hazard in tanker operations. Shore tank studies of simulated washing showed low-energy sparks when jets were directed either straight up or straight down. Comparison of small scale studies with full-scale washing operations. Review of studies on aerosol generation.	Van De Weerd Ref. #67 295-309 Smit Ref. #68 178-183 Gibson Ref. #72 80-81 Cooper Ref. #73 513-514 Chubb Ref. #74 71-87 Chubb Ref. #75 61-70 Bright Ref. #76 37-44	Yes Yes Yes Yes Yes Yes Yes

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.17 (continued)	b) All conductive insulated objects subject to impingement or condensation, including discharging pipe should be bonded to tank or equipment, or be grounded. Regarding the use of CO₂ in tanks & vessels: a) Jet of CO₂ generates static due to CO₂ snow. b) Putting CO₂ in vessel form of dry ice & allowing to vaporize is acceptable. c) CO₂ extinguishers should not be used for inerting.	No information. Discusses experiment done with CO₂ issuing from a cylinder of liquid carbon dioxide. Magnitude of charge on CO₂ related to pressure in cylinder and friction associated with impingement on surface. No information. Release of CO₂ at high velocity produces electrostatic and incendive discharges. Do not use CO₂ for inerting. Suggests design for antistatic CO₂ nozzle.	Banerji Ref. #53 431-433 Butterworth Ref. #26 161-169	Yes Yes
2.18	Regarding belts: a) If pulley is made from conducting material, charge will be dissipated through shaft & bearing.	Provides sample calculation of a pulley attached to a machine insulated from earth.	Strawson Ref. #12 15	Yes

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.18 (continued)	b) Use belt made of conductive material or apply conductive dressing. c) Avoid use of flat belts in hazardous areas; V-belts are acceptable.	Develops mathematical model of moving sheet material on grounded conducting roller. Simulates insulator belts. Charging depends on conductivity and speed of sheet. Experiments on an insulating belt slipping on metal roller. Shows that charge density exponentially approaches a limiting value as work done against friction is increased. Measurements of potentials generated on belts of rubber, neoprene, PVC & polyethylene running over metal rollers as a function of speed. Charge generation mainly influenced by surface resistivity. No information.	Horvath & Berta Ref. #32 259-263 Cunningham Ref. #80 1734-1736 Javadi & Napier Ref. #87 266-279	Yes Yes
2.19	Regarding filters & relaxation chambers: a) A liquid of low conductivity will accumulate static charge when pumped through a pipe; charge will dissipate when a voltage builds up.	Discusses study done on polyethylene pipe carrying kerosene to determine level of discharges from pipe surface. Conducted experiments involving flow of heptane through PVC tubing to measure liquid charge and tubing charge.	Mason Ref. #38 137-144 Keller Ref. #40 1433-1438	No. RP 2300 does not address plastic piping. No. RP 2300 does not address plastic piping.

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.19	(continued)	Survey of studies done by various workers regarding flow of hydrocarbons through nonconducting tubing. Briefly presents workers' conclusions. Measurements of charge density developed on polyethylene pipe by liquid flow. High resistivity liquids show virtually no charge decay. See Figure 6. Review of charge relaxation theory & summaries of studies by other workers. Theoretical predictions & supporting work in laboratory regarding hydrocarbon flow in conducting & nonconducting pipes. Studied iso-octane in metal container with filter arrangement. Studied current generated in toluene flowing in large scale SS pipe-line system. Electric current dependent on flow velocity, pipe diameter & pipe length. Purpose of study is to help develop equations that can predict current generation for large scale systems. Charge relaxation is of hyperbolic form. Charge density achieves a steady state value after a certain pipe length.	Leonard Ref. #14 23-27 Gibson Ref. #72 79 Cooper Ref. #73 512-515 Carruthers Ref. #25 169 Gibson & Lloyd Ref. #62 89-99 Bustin Ref. #30 210 Britton & Smith Ref. #1 55-56	No. RP 2300 does not address plastic piping. RP 2300 does not address plastic piping. Yes Yes and No Studies on current generation in flow not addressed in detail in RP 2003. Yes Yes

**SUMMARY OF LITERATURE SUPPORT
FOR RP 2003**

RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.19 (continued)	b) Presence of a filter can produce 10-200 times more charge in a system; no danger as long as liquid is kept in pipe.	Study conducted to observe relationship between chemical nature of fuel additives and charging tendency by passage through filters.	Leonard Ref. #14 28	Yes and No
		After passage through a filter, charge density of liquid increases 1-3 orders of magnitude. Suggestions for relaxation chambers.	Britton & Smith Ref. #1 55-56	Yes
		Not possible to predict effect of filter due to various types of construction.	Strawson Ref. #12 13	No
		Discusses charge relaxation downstream of a filter.	Britton & Smith Ref. #21 73	Yes
		Laboratory and full-scale tests on the loading of iso-octane and jet fuel after passage through a filter. Develops charge relaxation theory.	Bustin Ref. 330 209-216	Yes
		Comparison of relaxation criteria given by various codes.	Britton & Smith Ref. #21 71	No
		Relaxation time 2.	Eichel Ref. #13 166	In some cases.
		30 seconds is adequate for fuels regardless of conductivity.	Leonard Ref. #14 20	Yes
		Both 30 second constraint and 3 constraint can yield practical difficulties.	Britton & Smith Ref. #1 63, 55-56	Yes and No
	c) At least 30 seconds of relaxation time between filter and discharge point is necessary.			

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RP 2003 SECTION	WHAT RP 2003 SAYS	WHAT LITERATURE SAYS	LIT REF	IS RP 2003 RECOMMEN- DATION SUB- STANTIATED
2.19 (continued)	d) Relaxation time provided by sufficient piping volume. e) Ignore relaxation criteria for liquids with conductivities 50 pS/m.	No information. For general transfer operations, there is no ESD hazard if conductivity of liquid is 100 pS/m. Static charge accumulation is usually not significant for liquids with conductivities 50 pS/m, providing that liquid is handled in grounded metal equipment (with the exception of mists). Results of experiments verify that 50 pS/m is a safe value.	Loveland Ref. #27 9 Mancini Ref. #5 24 Britton & Smith Ref. #121 71	No Yes, but does not distinguish between insulated and noninsulated piping. Yes
2.20.1	Buried plastic tanks are not an electrostatic discharge problem.	Buried plastic tanks can be used if made of conducting polymeric material or if electrostatic build-up is controlled in system including earthed metal attachments.	Gibson & Harper Ref. #11 38-39	No
2.20.2	Test sample of aboveground glass-reinforced plastic tank showed it had a conductivity 100 times great as typical liquid product being handled.	Details accident cases involving ignition in a plastic drum and ignition in a ceramic-lined ball mill. Discusses the use of plastic containers & provides accident case study on fiberglass reinforced plastic tank. Conducted experiments involving flow of charged diesel into GRP tank. System also modeled on computer.	Loveland Ref. #27 8 Mancini Ref. #5 29-30 Lees Ref. #41 267-273	Yes, Addresses high levels of charge found having insulated properties. Yes, Addresses containers having insulating properties. Yes