Electrostatic Risk Assessment for Chemical Plants: Fire and Explosion Prevention

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An electrostatic discharge is one of the most concerning ignition sources for combustible substances. In order to carry out appropriate safety measures to prevent from ignition, it is necessary to understand correct fundamental phenomena of charging and discharging and to master the technology by considerable training. And next step, application of a risk assessment technology of static electricity is desired. Sumitomo Chemical Co., Ltd. has developed one of these technologies. This paper introduces one practical case study from it.

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Introduction

According to the White Papers on Fire Service which cover the past ten years (2008 – 2017), electrostatic discharge was deemed to be the most significant fire ignition source in facilities handling dangerous goods in seven separate years during this period, and was ranked as the second most common ignition source in the other years. Other ignition sources include contacting with high-temperature surfaces, overheating, electric sparks, open flames, and sparks from welding/fusing. It can be believed that one of the reasons why electrostatic discharge is ranked highest as an ignition source is because the electrostatic charging and discharging phenomena are difficult to understand, resulting in poor safety measures. Considering such circumstances, one can say that it is important to release and disseminate static electricity accident prevention technologies.

The author of this paper introduced the electrostatic hazards and safety measures in 2004 in SUMITOMO KAGAKU.1) Subsequently, in Japan the *Electrostatic Safety Guidelines*2) of the Japan Organization of Occupational Health and Safety (currently known as the Japan Organization of Occupational Health and Safety, National Institute of Occupational Safety and Health, Japan (hereafter referred to as JNIOSH)) was revised in 2007. Also, in 2013 the *Technical Guidelines for Electrostatic Safety* was released anew by the International Electrotechnical Committee (IEC).3), 4) Thus an environment has gradually been established in which advanced electrostatic safety technology is widely adopted. Along with this trend, the attempt to assess electrostatic hazard as a risk has begun. If we are able to assess electrostatic hazard as a risk, the following advantages can be expected: By making a relative comparison of the risks, the validity and adequacy of safety measures can be confirmed, and safety measures can be prioritized. However, although the risk assessment technology for fire and explosions has advanced in the field of leakage/ignition caused by equipment breakdown and/or malfunction, there is still no systematic risk assessment technology that focuses on electrostatic discharge as an ignition source. Therefore, Sumitomo Chemical developed a proprietary electrostatic risk assessment technology, incorporated it into the revised guidelines for electrostatic safety for Sumitomo Chemical and its group companies, and began its implementation in 2010. Subsequently, Ohsawa of JNIOSH has developed a method for electrostatic risk assessment (hereinafter referred to as the Ohsawa method), the guidelines5) of which were released in 2011. Sumitomo Chemical cooperated in its test operation and dissemination activities.

This paper will introduce the overseas trends in electrostatic risk assessment technologies and also the electrostatic risk assessment technology of Sumitomo Chemical along with implementation examples. Furthermore, as a reference, several cases will also be analyzed using the Ohsawa method, and the results of such comparison will be introduced. Lastly, as the basic knowledge required for understanding electrostatic risk assessments introduced in this paper, electrostatic countermeasures and electrostatic induction for conductors, electrostatic countermeasures for insulators and the discharge phenomenon will be explained. Those who want to systematically understand the electrostatic charge/discharge phenomena and countermeasure technology in more detail can refer to Reference[2)–4)] at the end of this paper.

Overseas Trends in Electrostatic Risk Assessment

Technical guidelines pertaining to electrostatic safety were released in the United Kingdom in 1980 and 1983, and those guidelines were amended in 1991.

They were later passed onto the CENELEC (European Committee for Electrotechnical Standardization), which in turn released technical guidelines in 2003. Subsequently, European countries have adopted guidelines similar to those released by the IEC in 2013.[3), 4)]

However, not all of these guidelines describe specific electrostatic risk assessment technologies that focus on the ignition likelihood of electrostatic discharge. Moreover, some books and papers on electrostatic risks and safety-measure technologies written by European researchers do not mention them at all.

Although the VDI (the Association of German Engineers) published the guidelines[6)–8)] introducing implementation examples of the dust explosion risk assessment on the VDI2263 series, using the matrix method in consideration of the ignition likelihood and level of damage, they also describe ignition sources other than electrostatic discharge, which can be assumed to occur in the target facility. Although they are very useful for those facilities, these guidelines do not comprehensively compile electrostatic risk assessment technologies.

The NFPA (National Fire Protection Association) in the United States has issued technical guidelines for electrostatic safety measures.[9)] However, as with the European guidelines, none of them comprehensively compiles electrostatic risk assessment technologies. A book regarding the hazard analysis on dust explosions published by the CCPS (Center for Chemical Process Safety) in 2017[10)] also does not contain any systematic commentaries for their electrostatic risk, but it introduces implementation examples of risk base assessment in some processes.

The key to the development of electrostatic risk assessment technology is how to determine the likelihood of ignition caused by electrostatic discharge. In the field of leakage ignition by liquefied petroleum gas, where more advanced quantitative risk assessment is conducted, abundant statistical data (e.g., the numbers of near miss, equipment breakdown/malfunctions and accidents) have been systematically collected over a long period of time for the purpose of developing a risk assessment technology. In this field, certain malfunctions, failures and likelihood of ignition–which are specifically applicable to the above assessment–have been determined in the form of numerical values. However, there is no known large-volume accumulation of statistical data over a long period of time with focus on electrostatic discharge as an ignition source. Therefore, it can be assumed that this fact may have caused the delay in developing a quantitative risk assessment technology that focuses on electrostatic discharge.

Electrostatic Risk Assessment of Sumitomo Chemical

Fig. 1 shows the implementation flow (Step 1) of electrostatic risk assessment. In Step 1 the necessity of implementation of the electrostatic risk assessment is determined in consideration of the likelihood of ignition and the level of its impact. First, the characteristics of the target substances are categorized, and then the probability of the target substance causing combustion or explosion is assessed under each category.

"*1" in **Fig. 1** is the process to determine whether the saturated vapor pressure of the flammable liquid has reached the concentration level that can cause an explosion. Sumitomo Chemical has set four safety factors, ranging from 5°C to 30°C, taking into account the error[11)] between the generally-known flash point and the true flash point. Regarding "*2," if no data on the flash point of the flammable liquid slurry cake itself is available, it will be determined by referring to the flash point of the flammable liquid alone. Regarding "*3," the Oxygen Concentration Control Criteria[12)] stipulated by the NFPA can be used as an evaluation criterion. "*4" is to determine the likelihood that a combustible

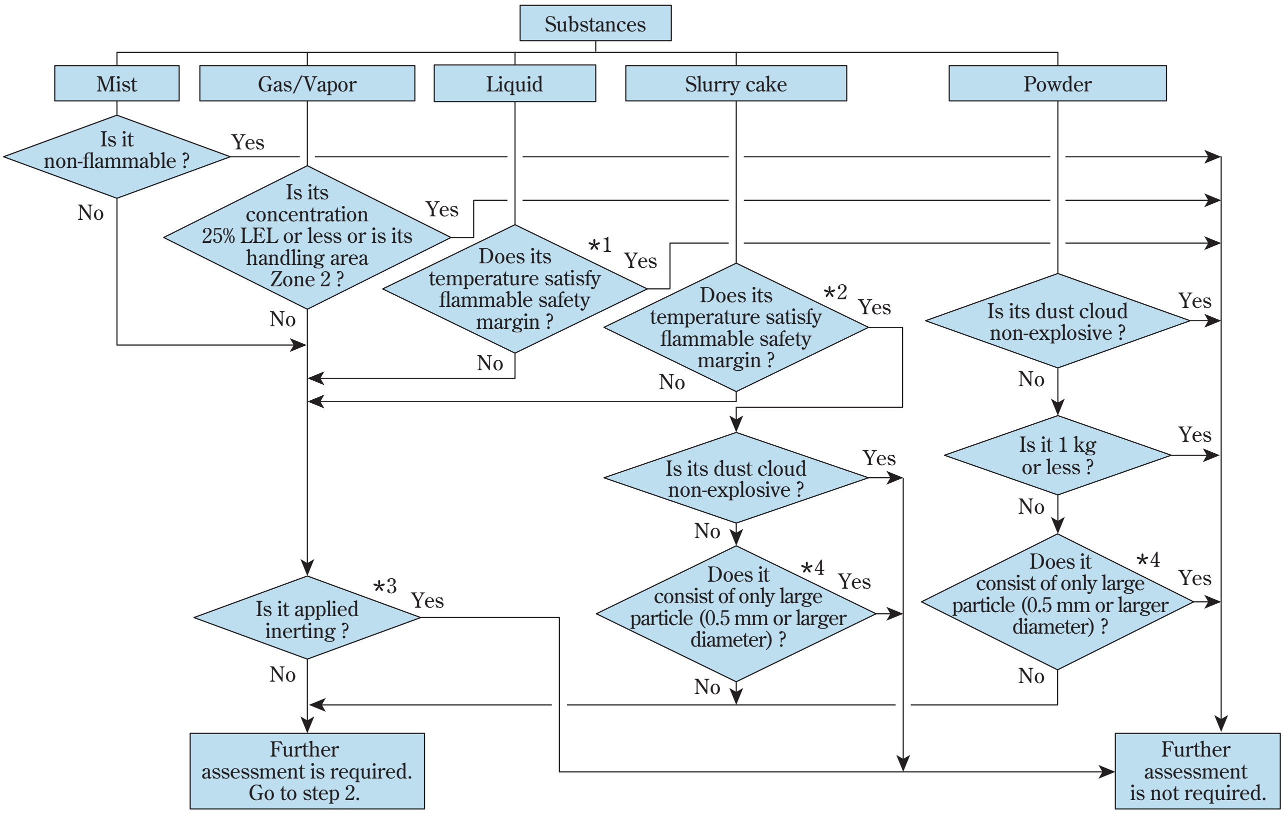


Fig. 1 Flow diagram for electrostatic risk assessment (Step 1)

dust-air mixture will form. Generally, when there are only particles with the size of 0.5 mm or larger, it can be determined as “Yes.” However, if the particle size cannot be confirmed, it can be determined based on the observation results of the particle size distribution or the suction method.[1)]

Once it has been determined that a more detailed assessment is required after applying the flow shown in **Fig. 1**, further electrostatic risk assessment is conducted by following the flow shown in **Fig. 2**. In this electrostatic risk assessment, as described in a later section (**Table 6**), the final risks are categorized into four rankings of A, B, C and D in the order of highest to lowest risk. If the risk concerned cannot be reduced to the rank C or D, another risk assessment is conducted, taking into account the safety measures. If the risk still cannot be reduced to C or D after this, the assessment will be repeated, taking into account the safety measures again. After all these procedures, if the risk ranking could still not be reduced to C or D, contact the in-house expert in electrostatic safety. The expert thus contacted will then reassess the risk by comprehensively evaluating the specific concerns of electrostatic charge/discharge, the energy of static discharge, and valid and feasible safety measures to provide advice regarding the safety measures. Thus the greatest feature of Sumitomo Chemical’s electrostatic risk control is that it has the following two-stage structure in the electrostatic risk assessment: In the first stage, the risk assessment is conducted by the technical staff at the plant and research department, and in the second stage the risk assessment is conducted by the in-house expert in electrostatic safety.

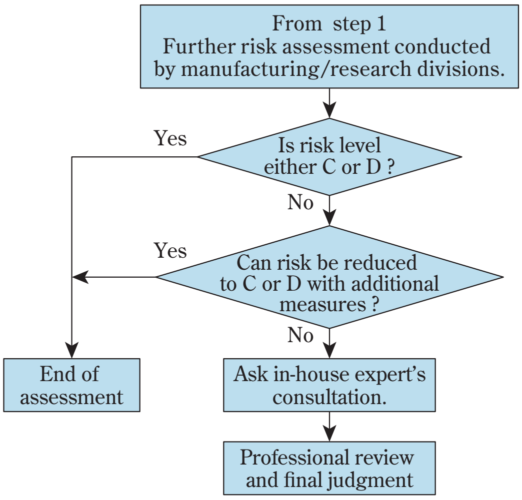


Fig. 2 Flow diagram for electrostatic risk assessment (Step 2)

1. Assessment of Likelihood

The likelihood of the occurrence of an electrostatic accident can be assessed by evaluating the possibility that each elements of the fire triangle (that is combustibles, oxygen and ignition source) shown in **Fig. 3** is simultaneously present in the same place and the same time, limiting the ignition source to static electricity alone. In the electrostatic risk assessment of Sumitomo Chemical, first, the likelihood that an explosive atmosphere may be formed is evaluated by simultaneously considering the possibility of the presence of both combustibles and oxygen of the fire triangle (this is referred to as the likelihood of forming the explosive atmosphere).

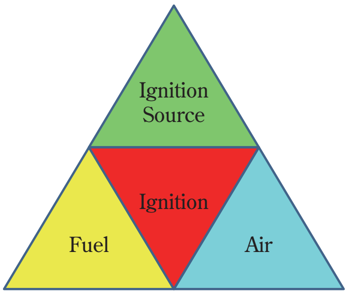


Fig. 3 The Fire Triangle

Table 1 shows the example of evaluation criteria for the likelihood of forming the explosive atmosphere that we use at Sumitomo Chemical. Zones are the standard classification determined by the IEC.[13), 14)] Zone 0 is a place in which an explosive atmosphere consisting of a mixture with air of combustible substances in the form of gas, vapor or mist is present continuously or for long periods or frequently. An example of Zone 0 is inside of a sealed container of flammable liquid. Zone 1 is a place in which an explosive atmosphere of a mixture with air of gas, vapor or mist is likely to occur occasionally in normal operation. An example of Zone 1 is an area near the upper opening of a container of flammable liquid that has no lid. Zone 2 is a place in which an explosive atmospheric mixture with air of combustible substances is not likely to occur during normal operation but, if it does occur, it will persist for a short period only. This zone includes places surrounding Zone 1. Zones 20, 21 and 22 are the dust explosive atmosphere, and the frequency and duration of occurrence of the hazardous explosive mixture are classified in the same way as for Zones 0, 1 and 2, respectively.

Table 1 Likelihood of formation of explosive atmospheres based on the Zone Classification

likelihood for formation of explosive atmosphere	Zone[13),14)]
High	Zone 0/Zone 20
Moderate	Zone 1/Zone 21
Low	Zone 2/Zone 22

In addition to the zone classification shown in **Table 1**, Sumitomo Chemical has established three levels of standard in-house classifications, where the likelihood of forming a dusty atmosphere conducive to explosion is classified into high, moderate and low based on the relationship between substance concentration in the atmosphere and the lower explosive limit (LEL) of gas, vapor or dust clouds.

Next, the likelihood of generating the incendive electrostatic discharge (hereinafter referred to as the likelihood of occurrence of incendive discharge) is determined through the following procedures: the maximum energy of electrostatic discharge that may be generated is estimated first and then the result of this estimation is compared to the minimum ignition energy (hereinafter referred to as the MIE) of combustibles. A simpler method which does not involve estimation of discharge energy is as follows: First, the approximate maximum discharge energy is estimated by specifying the type of electrostatic discharge and then this maximum value is compared to the minimum ignition energy. More specifically, the likelihood of occurrence of incendive discharge for gas/vapor and dust/mist clouds can be determined by referring to **Tables 2** and **3**, respectively.

Regarding the likelihood of occurrence of incendive discharge, in addition to the abovementioned methods, Sumitomo Chemical has set an original limit to the diameter of a dust/mist cloud, in accordance with the minimum ignition energy of dust and mist clouds. This limit is referred to as the control criteria[2)] provided by JNIOSH. By considering the abovementioned likelihood of forming an explosive atmosphere and likelihood of incendive discharge occurring, we can estimate the possibility that the fire triangle will be fulfilled and thereby raise the likelihood of electrostatic accidents. Sumitomo Chemical determines the likelihood that an electrostatic accident will occur through use of the information provided in **Table 4**.

2. Assessment of Severity of Damage

The severity of damage is determined by predicting

Table 2 Likelihood of occurring incendive discharge (gas/vapor)

Types of discharges (maximum energy ranges)	Likelihood of occurring incendive discharges		
	High	Moderate	Low
Corona discharge (0.1mJ)	H_2,C_2H_2	—	General gases/vapors
Brush discharge (5mJ)	General gases/vapors	Some gases/vapors	
Cone discharge (hundreds of mJ)	Almost all of gases/vapors		
Spark discharge (thousands of mJ)		—	—
Propagating brush discharge (tens of thousands of mJ)		—	—

Table 3 Likelihood of occurring incendive discharge (dust cloud)

Types of discharges (maximum energy ranges)	Likelihood of occurring incendive discharges		
	High	Moderate	Low
Corona discharge (0.1mJ)	—	—	All
Brush discharge (5mJ)	MIE ≦ 3mJ	3mJ < MIE ≦ 10mJ	10mJ < MIE
Cone discharge (hundreds of mJ)	MIE ≦ 100mJ	100mJ < MIE ≦ 1000mJ	1000mJ < MIE
Spark discharge (thousands of mJ)	All	—	—
Propagating brush discharge (tens of thousands of mJ)		—	—

Table 4 Likelihood of occurring electrostatic accident

		likelihood for formation of explosive atmosphere (obtained from **Table 1**)		
		Low	Moderate	High
Likelihood of occurring incendive discharge (obtained from **Table 2/3**)	Low	c	c	c
	Moderate	c	b	b
	High	c	b	a

Table 5 Severity of damages

		Criteria for judgment		
		Personnel	Facilities	Monetary
Severity	Low	no damage	small	small
	Moderate	slight	moderate	maderate
	High	heavy	large	large

Table 6 Fire/Explosion risk caused by electrostatic discharge

		Likelihood of occurring electrostatic accident (obtained from **Table 4**)		
		c	b	a
Severity (obtained from **Table 5**)	Low	D	C	B
	Moderate/High	C	B	A

human, material and financial damages. Sumitomo Chemical uses **Table 5** to determine the severity of damage pertaining to the electrostatic risk.

3. Electrostatic Risk

The electrostatic risk is determined in **Table 6** based on the estimation results from **Tables 4** and **5**. The risk is assessed by following the flow shown in **Fig. 2**, but if the risk cannot be reduced to C or D, the risk assessment would be repeated, taking into account the safety measures. If the risk ranking cannot finally be reduced to C or D, safety measures have to be determined in consultation with the in-house expert of electrostatic safety.

JNIOSH Electrostatic Risk Assessment (Ohsawa Method)

Development of the Ohsawa method$^{5)}$ was conducted during the period from 2008 to 2011, and its guide-

Table 7 Outline of each method

	Sumitomo Chemical Method	OHSAWA Method
Risk determination	Matrix method (Likelihood and Severity are taken into account in combination)	Severity and likelihood are not considered in combination.
Likelihood determination	Matrix method	Multiplication method
Parameters for likelihood determination	1) Likelihood for formation of explosive atmosphere (3 ranks)	1) Hazard level of explosion atmosphere (12 kinds of numerical values)
		2) Hazard level of electrification and electrostatic induction (7 kinds of numerical values)
	2) Likelihood of occurring incendive discharge (3 ranks)	3) Hazard Level of electrostatic discharge (4 kinds of numerical values)

lines were published in September 2011. **Table 7** shows a comparison between the Sumitomo Chemical and Ohsawa methods. First, while Sumitomo Chemical adopts a matrix method for the final risk assessment, the Ohsawa method focuses on the assessment of the likelihood of electrostatic discharge ignition, and thus the likelihood and severity of damage are not simultaneously taken into account when assessing the risk. For example, as shown in **Table 6**, even if the severity of damage varies among subjects, the general matrix method classifies them under the same risk level depending on the severity of the damage. On the contrary, in the Ohsawa method it is recognized that these subjects have different risk levels.

In the Ohsawa method, the likelihood of ignition by electrostatic discharge is obtained by multiplying the following three values: the hazard level of forming the combustible atmosphere, the hazard level of charge or electrostatic induction and the hazard level of electrostatic discharge. The result of this multiplication is referred to as the hazard level of ignition by static electricity. This corresponds to Sumitomo Chemical's "likelihood of the occurrence of an electrostatic accident."

There is no significant difference between the Sumitomo Chemical and Ohsawa methods in determining the hazard level of forming the combustible atmosphere. The result of multiplication of the hazard level of charge, that of electrostatic induction, or that of electrostatic discharge correspond to the likelihood of occurrence of incendive discharge in the Sumitomo Chemical method. Because in the Ohsawa method the likelihood of the occurrence of an electrostatic accident is given by several numeric values, more detailed relative comparison can be performed as compared to the Sumitomo Chemical method, which assesses the likelihood of the occurrence of an electrostatic accident using four levels of a, b, c and d.

This difference can be considered as coming from the different approach toward risk assessment between the Sumitomo Chemical method and the Ohsawa method as follows: while the electrostatic risk assessment used at Sumitomo Chemical Co., Ltd. has been positioned as a screening tool with a system that enables us to receive support from the in-house expert in electrostatic safety as the next step according to the assessment result (refer to **Fig. 2**), the Ohsawa method aims for solving issues by precisely applying the method for conducting a detailed investigation into risks.

1. Assessment of Hazard Level (Ohsawa Method)

In the Ohsawa method the hazard level of ignition by static electricity can be obtained by multiplying the three values obtained from **Tables 8**, **9** and **10**.

The values determined in **Table 8** represent the hazard level of forming the combustible atmosphere. This can be determined from the Zone concept regarding the explosive atmosphere (already mentioned in **Table 1**) and the Explosion Group. The term "hybrid" in **Table 8** means the atmosphere in which flammable gas/vapor atmosphere and dust cloud are coexisting.

The values determined in **Table 9** represent the hazard level of charging or that of electrostatic induction. An objects represented by the numerical value of 4 is an ungrounded conductor. Since an ungrounded conductor is electrically neutralized by grounding, its value changes from "4" to "0" in **Table 9**. Because insulators have less electric charge that can be transferred even after being charged as compared to ungrounded conductors, it will be categorized under value 2 or 3, depending on the presence of leaked electric charge. Apart from this, when performing any operation that involves strong electrostatic charging such as a forced

Table 8 Hazard level of explosion atmosphere[5]

	IIC/IIC hybrid	IIB/IIB hybrid	IIA/IIA hybrid	III
Zone 0/Zone 20	20	15	10	5
Zone 1/Zone 21	12	9	6	3
Zone 2/Zone 22	4	3	2	1
No formation	0	0	0	0

Table 9 Hazard level of electrification and electrostatic induction[5]

Charging level based on conductivity/resistivity	With charge leakage	Without charge leakage	With charge promotion
High	2	3	× 2
Moderate	1	3	× 2
Low	0	4	× 2

Table 10 Hazard level of electrostatic discharge

Types of discharge	Hazard level for electrostatic discharge
Spark discharge	5
Brush discharge	3
Propagating brush discharge	3
Cone discharge	2
Corona discharge (IIC)	1

friction applied using mechanical power, the above values should be doubled.

The values determined in **Table 10** represent the hazard level of electrostatic discharge. In this table the difference between the values of the hazard level of electrostatic discharge are based on the result of analysis conducted as follows: The ignition-trouble information provided by the cooperating company in developing the assessment method was analyzed by the ignition source and then each incident was weighed in the order of highest to lowest in terms of the frequency of occurrence.

2. Severity of Damage (Ohsawa Method)

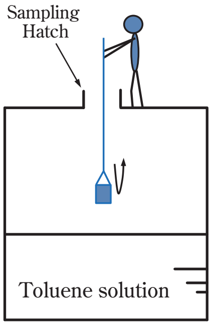
In this method the severity of human and financial damages are ranked under the three rankings of A, B, and C in the order of highest to lowest in terms of the severity.

3. Risk of Ignition by Electrostatic Discharge (Ohsawa Method)

The risk of ignition by electrostatic discharge is expressed by adding the alphabet representing the severity of damage to the numerical value representing the hazard level of ignition by static electricity. For example, it can be expressed as 60B or 360A.

Examples of Electrostatic Risk Assessment

This section introduces an electrostatic risk assessment that is made, for example, during the sampling operation. In this operation, toluene, which is the main ingredient of the content liquid in the large tank, will be extracted (by opening the tank hatch located at the top of the tank) as a sample using the method shown in **Fig. 4**. Then, **Fig. 5** indicates the areas where electrostatic discharge may occur when conducting the operation shown in **Fig. 4**.



<Conditions>
Temp.; 10 degree C
Humidity; 25%
Flash point (as pure toluene); 4degree C
Conductivity (as pure toluene); <1pS/m (Insulative)
MIE (as pure toluene); 0.24mJ
Inside tank atmosphere; Air
Volume of sampling container; 1L
Material of sampling container; metal

Fig. 4 Illustration of sampling from top of a tank containing flammable liquid

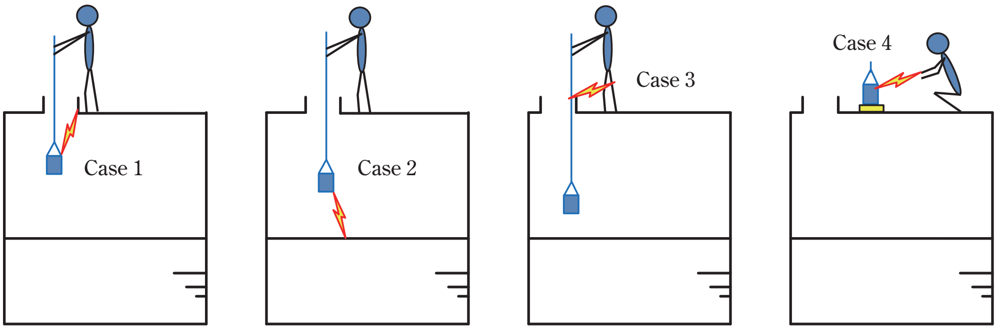


Fig. 5 Cases of each geometry where electrostatic discharge is concerned

1. Results of Risk Assessment (Sumitomo Chemical Method)

Table 11 shows the results of risk assessment of the samples shown in **Fig. 4**. The following is a detailed explanation of **Table 11**.

(1) Case 1

(i) Likelihood That an Explosive Atmosphere Will Form

1-1, 1-2 and 1-4: Because the area of concern of electrostatic discharge is inside the tank, the likelihood is deemed to be “high.”

1-3: This is a case in which nitrogen is added as a safety measure. Because the area of concern of electrostatic discharge is near the opening from which a sample was collected, it is assumed that the effect of nitrogen inerting may not be adequate, and thus the likelihood is deemed to be “moderate.”

(ii) Likelihood of the Occurrence of Incendive Discharge

1-1 and 1-3: Because the electrical potential of the ungrounded sampling container may increase due to the friction with toluene or the electrostatic induction from the charged toluene in the container, there is a possibility that incendive spark discharge may be generated between the sampling container and the metal part inside the tank. Thus, the likelihood is deemed to be “high.”

1-4: In this case, toluene has been sufficiently neutralized electrically to prevent ignition from electrostatic discharge as in Case 2, however, not sufficiently to ensure ignition is prevented as in Case 1. Thus, the likelihood is deemed to be “high,” as is the case with 1-1 and 1-3.

1-2: Because the electrical potentials of the grounded sampling container and metal part inside the tank are both determined as 0[V] and thus there is no risk of discharge, the likelihood is deemed to be “low.”

(iii) Likelihood of the occurrence of an electrostatic Accident

Based on **Table 4**, the likelihood of an electrostatic accident is “a, c, b, a” for from 1-1 to 1-4 in order of the suffix number.

Table 11 Risk analysis result (Sumitomo Chemical Method)

Case	Sub No.	Safety measures	Likelihood			Severity (personnel) H: High M: Moderate	risk	Risk reduction level by taking countermeasures
			formation of combustible atmosphere H: High M: Moderarte L: Low	Incendive discharge H: High M: Moderate L: Low	Fire or explosion caused by static discharge			
1	1-1	None	H(Zone 0)	H(Spark)	a	H	A	–
	1-2	Grounding (personnel/container)	H(Zone 0)	L(No discharge)	c	H	C	Effective
	1-3	Inerting with nitrogen	M(Zone 1)	H(Spark)	b	H	B	Effective but insufficient
	1-4	Charge relaxation (toluene)	H(Zone 0)	H(Spark)	a	H	A	None
2	2-1	None	H(Zone 0)	H(Brush)	a	H	A	–
	2-2	Grounding (personnel/container)	H(Zone 0)	H(Brush)	a	H	A	None
	2-3	Inerting with nitrogen	L(Zone 2)	H(Brush)	c	H	C	Effective
	2-4	Charge relaxation (toluene)	H(Zone 0)	L(No incendive discharg)	c	H	C	Effective
3	3-1	None	M(Zone 1)	H(Spark)	b	H	B	–
	3-2	Grounding (personnel)	M(Zone 1)	L(No discharge)	c	H	C	Effective
	3-3	Inerting with nitrogen	M(Zone 1)	H(Spark)	b	H	B	None
	3-4	Charge relaxation (toluene)	M(Zone 1)	H(Spark)	b	H	B	None
4	4-1	None	M(Zone 1)	H(Spark)	b	M-H	B	–
	4-2	Grounding (personnel/container)	M(Zone 1)	L(No discharge)	c	M-H	C	Effective
	4-3	Inerting with nitrogen	M(Zone 1)	H(Spark)	b	M-H	B	None
	4-4	Charge relaxation (toluene)	M(Zone 1)	H(Spark)	b	M-H	B	None

(iv) Severity of Damage

Since an ignition inside the tank can seriously impact the safety of the sample collecting personnel who stand on the top board of the tank, the severity of damage is deemed to be "high" (must be assessed without taking into account the validity of safety measure).

(v) Risk

Based on **Table 6**, the risk will be A, C, B and A from 1-1 to 1-4 in order of the suffix number.

Regarding Case 1, the above results have revealed that the risk could not be accepted without additional safety measures but could be reduced to the acceptable level by grounding the metal sampling container. Additionally, the result of the analysis on case 1-3 indicates that the risk could not be reduced to the acceptable level if only inerting is adopted and grounding the metal container and personnel is not adopted.

(2) Case 2

(i) Likelihood That an Explosive Atmosphere Will Form

2-1, 2-2 and 2-4: As with Case 1, because the area of concern of electrostatic discharge is inside the tank, the likelihood is deemed to be "high."

2-3: This is a case in which nitrogen is added as a safety measure. Because it can be assumed that the effect of nitrogen inerting is greater than Case 1, the likelihood is deemed to be "low."

(ii) Likelihood of the Occurrence of Incendive Discharge

2-1, 2-2 and 2-3: Because electrostatic discharge occurs between toluene which is an insulator and the sampling container which is a conductor, there is a concern that incendive brush discharge may occur. Thus, the likelihood is deemed to be "high." Additionally, regarding 2-1, because the sampling container is ungrounded, there is a possibility that its electric potential may increase due to the electrostatic induction from charged toluene, thus reducing the potential difference between the container and the toluene. This may allow electric discharge energy to be smaller than that of 2-2. However, because the likelihood of occurrence of incendive discharge is positioned as a screening tool at Sumitomo Chemical, this difference is not considered.

2-4: In this case, it is assumed that the static electricity has been removed from toluene to the safe level as a safety measure. It is therefore expected that even if brush discharge occurs, it will not be incendive, and thus the likelihood is deemed to be "low."

(iii) Likelihood of the occurrence of an electrostatic Accident

Based on **Table 4**, the likelihood of the occurrence of an electrostatic accident is a, a, c and c from 2-1 through 2-4 in order of the suffix number.

(iv) Severity of Damage

As with Case 1, it is deemed to be "high."

(v) Risk

Based on **Table 6**, the risk will be A, A, C and C from 2-1 to 2-4 in order of the suffix number.

Regarding Case 2, the above results have revealed that the risk could not be accepted without additional safety measures, but it could be reduced to an acceptable level by adding nitrogen or removing the electric charge from toluene.

Additionally, the result of the analysis on case 2-2 indicates that the discharge risk shown in Case 2 cannot be reduced to the acceptable level if the grounding measure (in which the metal sampling container is grounded) alone is implemented and other measures (such as the nitrogen inerting or removing a sufficient amount of electric charge from toluene (i.e., taking a sufficient relaxation time)) are neglected.

(3) Case 3

(i) Likelihood That an Explosive Atmosphere Will Form

3-1, 3-2 and 3-4: Because the area of concern of electrostatic discharge is outside the tank, where is near the opening from which sample was collected, it is considered to be Zone 1. Thus, the likelihood is deemed to be "moderate."

3-3: This is a case in which nitrogen is added as a safety measure. Assuming that the effect of reducing the oxygen concentration by adding nitrogen is limited to inside the tank, the likelihood is deemed to be "moderate," as with other cases.

(ii) Likelihood of the Occurrence of Incendive Discharge

3-1, 3-3, 3-4: In this case, the electrostatic countermeasures for the human body are inadequate (e.g., not wearing antistatic shoes; inadequate leakage resistance due to the insulation paint applied on the top board of the tank, which is the foothold of the sample collection personnel). Because there is a possibility that the electric potential of the human body (sample collecting personnel) will increase, thus causing incendive spark discharge between the sample collecting personnel and grounded conductor near the sampling hatch, the likelihood is deemed to be "high."

3-2: In this case, electrostatic countermeasures for the human body have been implemented as safety measures. The electric potentials of the human body and the nearby grounded conductor are deemed to be 0[V], and this eliminates the concern that an incendive spark discharge will occur. Thus, the likelihood is deemed to be "low."

(iii) Likelihood of the Occurrence of an Electrostatic Accident

Based on **Table 4**, the likelihood of the occurrence of an electrostatic accident will be b, c, b and b for 3-1 to 3-4 in order of the suffix number.

(iv) Severity of Damage

Although the ignition occurs outside the tank, it would be near the opening for sampling, and it is feared that flame may flashback into the tank. Therefore the severity of damage is deemed to be "high," as with cases 1 and 2, both of which assume that ignition would occur inside the tank.

(v) Risk

Based on **Table 6**, the risk will be B, C, B and B for 3-1 to 3-4 in order of the suffix number.

Regarding Case 3, the above results have revealed that the risk can not be accepted without additional safety measures. However, it can be reduced to the acceptable level by implementing electrostatic countermeasures for sample-collecting personnel.

(4) Case 4

(i) Likelihood That an Explosive Atmosphere Will Form

4-1, 4-2, 4-3 and 4-4: Because the area of concern of electrostatic discharge is outside the metal sampling container which contains toluene, it is considered to be Zone 1. Thus, the likelihood is deemed to be "moderate."

(ii) Likelihood of the Occurrence of Incendive Discharge

4-1, 4-3 and 4-4: In this case, electrostatic countermeasures for the human body or those for the metal container (or both) are inadequate. If those for the human body are inadequate (e.g., not wearing antistatic shoes and work clothing; inadequate leakage resistance due to the insulation paint applied on the top board of the tank, which is the foothold of the sample collecting personnel), there is a possibility that the electric potential of the human body (sample collecting personnel) may increase, thus causing incendive spark discharge between the sample collecting personnel and the sampling container. Thus, the likelihood is deemed to be "high." Furthermore, if the metal sampling container is not grounded, the electric potential may increase due to the electrostatic induction from charged toluene inside the sampling container (or due to some other reasons), thus causing a incendive spark discharge between the container and human body. Thus, the likelihood is deemed to be "high" as well.

4-2: In this case, electrostatic countermeasures for both the human body and the metal sampling container are undertaken. The electric potential of the human body and the metal sampling container are deemed to be 0[V], and this eliminates the concern that an incendive spark discharge will occur. Thus, the likelihood is deemed to be "low."

(iii) Likelihood of the Occurrence of an Electrostatic Accident

Based on **Table 4**, the likelihood of the occurrence of an electrostatic accident will be b, c, b and b for 4-1 to 4-4 in order of the suffix number.

(iv) Severity of Damage

The area of ignition is outside the tank. However, it is further away from the opening for sampling, comparing to Case 3. Thus two scenarios can be assumed: one is that the cause of ignition is limited to the toluene vapor in the metal sampling container; and the other is that flame backfires into the tank. Thus, the likelihood is deemed to be "moderate to high."

(v) Risk

Based on **Table 6**, the risk will be B, C, B and B for 4-1 to 4-4 in order of the suffix number.

Regarding Case 4, the above results have revealed that the risk is not acceptable without additional safety measures. However, it could be reduced to the acceptable level by implementing electrostatic countermeasures for the metal sampling container and the sample collecting personnel.

The assessment examples and their underlying concepts have thus been introduced in detail. It can be recognized that none of the countermeasures mentioned above (i.e., grounding the metal sample container, electrostatic countermeasures for sample-collecting personnel, oxygen concentration control by inserting nitrogen, and removal of electric charge from toluene) can accommodate all areas of concern in the above cases. As introduced above, conducting two types of risk assessments (one is with safety measures and the other is with no safety measures) and organizing the results of these assessments in a table can make it easier to see which safety measures are effective to what types of concerns. It also makes it easier for ones to predict risks when such safety measures are not employed. These results can be used as an operation standards sheet or an instruction material.

2. Risk Assessment Results (Ohsawa Method)

Next, **Table 12** shows the results of the assessment conducted on the same cases using the Ohsawa method. The details will be left out here, but the cases about which ignition is a concern were classified into five electrostatic-discharge hazard levels, ranging from 0 to 200, depending on the hazard level. According to the results of this analysis, the cases of which electrostatic-discharge hazard level is 12 or lower are equivalent to those for which the risk using the Sumitomo Chemical Method is ranked as C or D (cases that require neither enhancement in the safety measures nor consultation with the in-house expert).

Basic Knowledge Regarding Electrostatic Risk Assessment Introduced in This Paper

Due to the limited space, it is impossible to comprehensively introduce all the phenomena required for understanding the electrostatic risk assessment (such as the electrostatic charging/discharging phenomena) or various types of electrostatic countermeasures. Accordingly, the minimum knowledge required for understanding the electrostatic risk assessment introduced thus far will be explained below.

1. Grounding (Earthing) and Bonding

As shown in **Fig. 6**, the electric potential (unit is [V]) a conductor such as a metal object or the human body

Table 12 Risk analysis result (OHSAWA Method)

Case	Sub No.	Safety measures	Hazard Level				Severity (personnel)	Risk	Risk (Sumitomo Chemical Method)
			Explosion atmosphere	Electrification and electrostatic induction	Electrostatic discharge	Ignition caused by electrostatic discharge			
1	1-1	None	10(Zone 0)	4(Container)	5(Spark)	200	A	200A	A
	1-2	Grounding (personnel/container)	10(Zone 0)	0(Container)	not expected	0	A	0A	C
	1-3	Inerting with nitrogen	6(Zone 1)	4(Container)	5(Spark)	120	A	120A	B
	1-4	Charge relaxation (toluene)	10(Zone 0)	4(Container)	5(Spark)	200	A	200A	A
2	2-1	None	10(Zone 0)	2(liquid)	3(Blush)	60	A	60A	A
	2-2	Grounding (personnel/container)	10(Zone 0)	2(liquid)	3(Blush)	60	A	60A	A
	2-3	Inerting with nitrogen	2(Zone 2)	2(liquid)	3(Blush)	12	A	12A	C
	2-4	Charge relaxation (toluene)	10(Zone 0)	0(liquid)	not expected	0	A	0A	C
3	3-1	None	6(Zone 1)	4(personnel)	5(Spark)	120	A	120A	B
	3-2	Grounding (personnel/container)	6(Zone 1)	0(personnel)	not expected	0	0	0A	C
	3-3	Inerting with nitrogen	6(Zone 1)	4(personnel)	5(Spark)	120	A	120A	B
	3-4	Charge relaxation (toluene)	6(Zone 1)	4(personnel)	5(Spark)	120	A	120A	B
4	4-1	None	6(Zone 1)	4(personnel/container)	5(Spark)	120	A ~ B	120A 120B	B
	4-2	Grounding (personnel/container)	6(Zone 1)	0(personnel/container)	not expected	0	A ~ B	0A 0B	C
	4-3	Inerting with nitrogen	6(Zone 1)	4(personnel/container)	5(Spark)	120	A ~ B	120A 120B	B
	4-4	Charge relaxation (toluene)	6(Zone 1)	4(personnel/container)	5(Spark)	120	A ~ B	120A 120B	B

is maintained at 0[V] by electrically connecting it to the ground which is at 0[V]. This is referred to as grounding or earthing. Bonding means to cause the electric potential of a conductor to be the same as that of another conductor by electrically connecting the two conductors. In this case, if the destination conductor has been grounded, the same effect as that achieved by grounding can be obtained. In principle, the electric potential of a conductor present in a flammable/combustible atmosphere must be maintained at 0[V] by means of grounding or bonding. However, attention must be paid to the fact that even if a conductor has been grounded, incendive discharge may occur if a charged object comes close to a grounded conductor. Although the IEC's Technical Guidelines[3] introduce an exceptional case which does not require the grounding of small metal parts (such as a bolt), in order to apply such a standard, proper assessment and judgment are required. Therefore, it is ideal to apply this standard under the supervision of an expert in electrostatic safety. This section introduces some precautions for grounding and bonding.

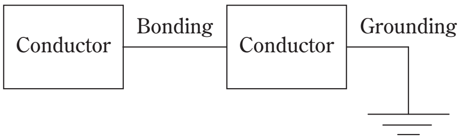


Fig. 6 Grounding and bonding

(i) Grounding and bonding are only effective on conductors. Because standard plastics are insulators, in most cases grounding or bonding is useless for such plastics.

(ii) If the electric potential of an ungrounded conductor has increased, the concern arises that incendive discharge may occur upon the installation of a ground wire using clips or similar objects. It is therefore necessary to perform this operation when the explosive atmosphere is not present.

(iii) When a detachable grounding has become detached during operation and is hastily reinstalled, it can be hazardous (due to the reason described in the above (ii)).

(iv) Electrostatic countermeasures for the human body include managing the floor conductivity and wearing antistatic shoes and work clothing. It is particularly important to undertake countermeasures for the floor and shoes because by electrically connecting the human body and the ground through the floor and shoes, the electric potential of the human body can be maintained at 0[V]. Therefore, if countermeasures for the floor and shoes are implemented sufficiently, even though the sample collecting personnel is not wearing the antistatic work clothing, the degree of hazard is within an acceptable range unless the person puts on and/or takes off his/her work clothing within the explosive atmosphere. Conversely, even if the sample collecting personnel is wearing the antistatic work clothing, if the countermeasures for the floor and shoes are insufficient, often it can lead to a hazardous situation.

For the floor safety management, the leakage resistance of the floor is measured. If nonconductive paint is applied to the floor, or the floor surface is contaminated from oil or powder, the required amount of leakage resistance may not be obtained.

For the safety management of shoes, using a measuring apparatus that can measure the resistance between the sole and palm makes it possible to undertake safety measures in consideration of the resistance of the inner soles and socks as well.

2. Electrostatic Induction

In most of the normal electrostatic charge phenomena, an electrification (= deficiency and excess in electric charge) occurs subsequent to the contact, friction and separation processes, which frequently causes an increase in the electric potential. However, it is also necessary to understand electrostatic induction which occurs without having any contact, friction or separation processes.

Fig. 7 shows a schematic diagram of a person receiving static discharge shocks focusing on charge transfer and potential increase/decrease caused by electrostatic induction. It consists of eight illustrations and shows a scenario going from the 1st to the 8th in that order, and a negatively charged flexible container (hereinafter referred to as the FIBC), a person who is not grounded because he/she is wearing non-antistatic shoes, and a grounded metal plate are drawn in . The first illustration shows the state in which no electrification or potential increase is present. The second illustration shows the FIBC approaching to the person from left infinity. Although it is not visible, it appears that positively charged ions and the like in the person will be

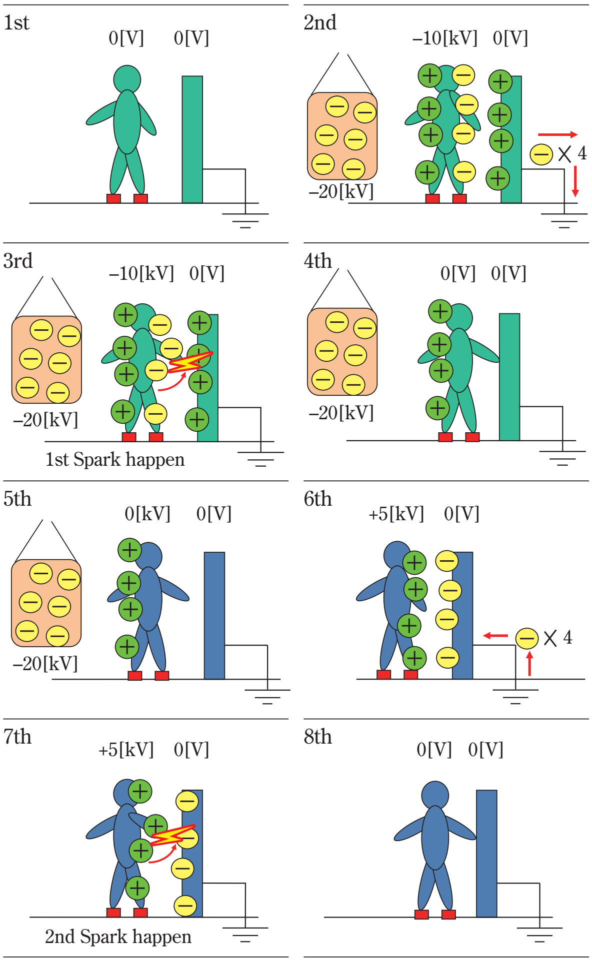


Fig. 7 An example of discharge shocks by electrostatic induction

drawn to the FIBC, and those that have been negatively charged will be repelled by the FIBC and move away from it. Consequently, the positive and negative charges will appear in the left side and right side of the person, respectively. The person is standing between the grounded metal plate having an electrical potential of 0[V] and the negatively-charged FIBC and this results in the negative potential of the person increasing. Affected by this phenomenon, the free electrons in the left side of the metal plate will move to the ground due to the repulsion, thereby generating a positive charge on the surface of the left side of the metal plate. When this happens, although an electric charge distribution is generated at the surface of the human body, it is not accurate to state that the person has been electrically charged, because there is neither a deficiency nor an excess in electric charge in the person. It is more appropriate to state that although the human body has not been electrically charged, its electric potential has increased due to the electric-charge distribution caused by the electrostatic induction. If the person attempts to touch the grounded metal plate in this state, an electrostatic discharge (electrons running from the fingertip to the grounded metal plate) occurs due to electric breakdown of air which happens at an electric field strength of 3×10^6 [V/m] (see the third illustration).

The distance that causes this electric discharge during general human activities is about a few millimeters. This type of discharge not only gives us an intense pain, but also can be an ignition source for flammable gas, flammable liquid vapor, and combustible dust clouds. The fourth illustration shows the state in which the operator has touched the metal plate with his/her fingertip immediately after the occurrence of an electric discharge. The person and the metal plate then become bonded, and because the metal plate has been grounded, the human body will also become grounded. Consequently, the person's electric potential will become 0[V].

The fifth illustration shows the operator removing his/her fingertip from the metal plate in the above state. Although it can be said that the person has become electrified due to the excess positive charges, the human potential remains at 0[V]. This is a good example to show that electrification does not necessarily mean an increase in the electric potential. However, this is because there is a negatively charged FIBC nearby. As the FIBC moves away infinitely, the positive potential of human body will appear as it would normally would (see the sixth illustration). Subsequently, when the person attempts to touch the metal plate once again, a discharge will occur (see the seventh illustration) the human potential will become 0[V] again (see the eighth illustration). If the person removes his/her fingertip from the metal plate, the status will then be as shown in the first illustration.

Thus the person will receive an electric shock twice in a stationary state during the process in which the FIBC approaches closer and then moves away. It is necessary to take precautions during filling and discharge processes of combustible powder because such kinds of electrostatic discharge mentioned above may happen.

Electrification is also caused by an electrostatic induction when a person walks around. When this happens, the shoe soles become electrified and cause the charge distribution between the lower and upper part of the person to have opposite polarities, thus increasing the person's electrical potential. When a person stands up from the sofa, the contact/friction/separation between clothing and sofa will lead generation of charge distribution on clothing, thus increasing electrical potential of clothing. The increased electrical potential of clothing causes electrostatic induction, thus increasing the person's electrical potential. Such knowledge can also be applied as a safety measure when filling the gasoline tank at a self-service gas station.

3. Relaxation Time for Insulative Liquid as a Charge-Removing Measure

Most flammable liquids such as toluene have high resistivity. However, the hazard level of electrification of an insulative liquid in a grounded metal container can be reduced to a safe level when the liquid has been left for the duration of a specified time (relaxation time) which can be determined based on electrical conductivity of the liquid.

Regarding the relaxation time, although it is appropriate to determine the starting point of the relaxation time to be the point in time when the operation (i.e., situation) causing a charge separation ends, if insoluble solids or impurities are present in the liquid, and if this solid is slowly settling or coming to the surface, the liquid could become electrically charged again. If this happens, the relaxation time will be insufficient. Generally, it is difficult to confirm whether such electrical charging from solids surfacing or settling is occurring. It is therefore necessary to keep in mind that such solids affect the reliability and certainty of the relaxation time as a safety measure.

4. Types of Electric Discharges

This section introduces spark and brush electric discharges only.

A spark discharge occurs between two conductors, such as the discharge that occurs between a door knob and the fingertips. In order for a spark discharge to occur between two conductors, at least one of them must be ungrounded and therefore pose increased potential. When a person feels an electric shock by touching a door knob, it is very often the person's body but not the door knob which is ungrounded and thus has an increased potential.

The electrostatic capacity C (unit is F: farad) can be defined for an ungrounded conductor. If the electric potential V is known, then the discharge energy W (unit is J: joule) can be calculated using the relational expression $W = 0.5\ CV^2$, thus making it possible to discuss the likelihood of ignition by comparing the scale of the discharge energy W with that of the minimum ignition energy of the flammable substances.

A brush discharge makes a crackling noise and gives minor pain when taking off a sweater in winter, for example. It occurs between an electrified insulator (an object that hardly conducts electricity) and a conductor when the conductor comes closer to the insulator. Because it is not possible to determine the electrostatic capacity of an insulator that causes a brush discharge, its discharge energy cannot be estimated using the same simple formula as that used for a conductor. Although a brush discharge cannot ignite flammable substances as readily as a spark discharge can, it is said that it can ignite flammable gas or flammable liquid vapor with a minimal ignition energy of up to approximately 3 mJ.

Conclusion

To prevent fire and explosion caused by electrostatic discharge, it is necessary to notice a hazard(s), understand and assess the noticed hazard(s), and devise and implement appropriate safety measures based on the result of assessment. Sumitomo Chemical has established a variety of education programs (some of which are classroom lectures and others which are hands-on experiments) required for properly assessing the hazards. If you are interested in these programs, please see the reference documents15), 16). Electrostatic accidents happen on a regular basis, and are considered to be one of the highest causes of fire at facilities where dangerous materials are handled even in the present time. Because a fire accident during an operation by an employee can cause bodily injury or death, it is crucial to inform workers of specific electrostatic hazards involved in each operation and to convey the need for safety measures in a way that is easy to understand. We hope that this paper will help eliminating electrostatic accidents even slightly. Additionally, please refer to the reference documents17), 18) for electrostatic risk assessment methods that were not introduced in this paper.

Lastly, we extend our heartfelt appreciation to Dr. Atsushi Ohsawa, of JNIOSH, for his guidance with respect to the implementation examples of the method that bears his name.

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