Evaluation and Prevention of Electrostatic Hazards in Chemical Plants

Sumitomo Chemical Co., Ltd.
Process & Production Technology Center
Kiyoshi Ota

Nowadays, electrostatic theories are usefully applied to various industries. On the other hand static electricity cause ESD (electrostatic discharge) problem in high technology industries or fire and explosion in chemical industries. In order to prevent incidents caused by electrostatic discharge, it is important that operators or staffs working in chemical plants find electrostatic potential hazards and have consultations with safety experts. Electrostatic charge and discharge phenomena, countermeasures against static electricity and some methods for evaluating electrostatic hazards are described in this paper.

This paper is translated from R&D Report, "SUMITOMO KAGAKU", vol. 2004-Ⅱ.

Introduction

Because of eye-opening results in recent years in research on electrostatic phenomena, there have been effective applications in industry in copiers, dust collectors and the like, but there has been no end to the disasters due to static electricity, such as problems of damage due to electrostatic discharge in the electronics industry where it is often called ESD and fires and explosions in the chemical industry. While there is specialized knowledge for the prevention of electrostatic disasters, it is most important that the operators and staff actually engaging in production in factories be intimate with the correct knowledge concerning electrostatic safety, discover the potential causes of electrostatic hazards and consult experts on security and disaster prevention. This article will be limited to the prevention of fires and explosions due to static electricity, and along with introducing discharge phenomena as well as electrostatic charges that people should know about for preventing electrostatic disasters when working in production sites at factories, we will introduce disaster prevention technology and electrostatic hazard evaluation methods implemented by Sumitomo Chemical.

Explanation of Terms for Static Electricity

Here we will give a simple explanation of static electricity terminology as it relates to this article.

1) Volume resistivity

Units: Ω·m. This is the unit cross-sectional area and unit length resistance value. It is an easy criterion for electrostatic leakage. Conductivity (Units S/m) and volume resistivity have reciprocal relationship.

2) Conductors and Insulators

These are classified according to volume resistivity as shown in **Fig. 1**.1) While grounding is effective as a countermeasure for static electricity with conductors, little or no grounding effect can be expected with insulators. Moreover, ungrounded conductors, known as "floating conductors," are electrostatically very dangerous. The human body can become a floating conductor.

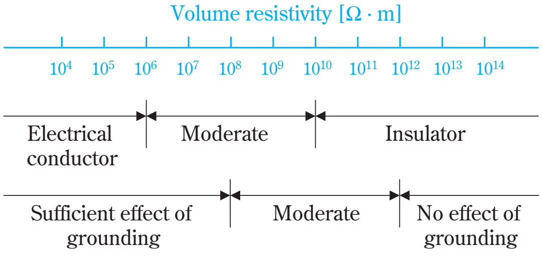


Fig. 1 Volume resistivity and effectiveness of grounding

3) Leak resistance2)

Leak resistance is the total resistance between an object and the earth, combining the resistance of the object itself, the contact resistance for electrodes and the like, the grounding resistance, etc., and the charge of conductors depends upon leak resistance in general.

4) Electric potential

Units: V. This is an indirect measure of the size of electrostatic charge.

5) Charge

Units: C/g. This expresses the size of the electrostatic charge.

6) Electrostatic capacity

Units: F. When the charge of an electrified conductor is Q [C] and the potential V [V], the electrostatic capacity C [F] is given by $C = Q/V$. In addition, the energy U [J] stored in the conductor at that time is given by $U = 1/2 \cdot C \cdot V^2$, 3) and the ignition hazard can be evaluated by comparing this to the minimum ignition energy of combustible materials.

7) Electric field strength

Units: V/m. If the potential at any two points is given, the electric field strength is obtained by dividing the difference in electric potential by the distance between the two points. This is important as an index of whether there is a possibility of a discharge occurring or not.

8) Dielectric constant

Units: F/m. This is the ε of the relationship between dielectric displacement D and electric field E, $D = \varepsilon E$. This is a physical property necessary for the electric field calculations introduced in this article.

9) Electrostatic induction

As is shown in Fig. 3 (j), when there is an insulated conductor close to a charged body, a charge separation occurs on the surface of the conductor because of the electrostatic induction from the charged body. This is called electrostatic induction.

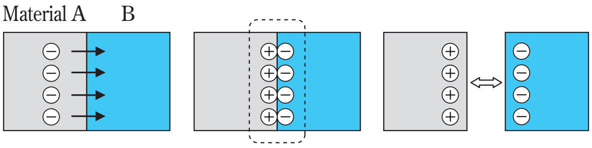
10) Grounding and bonding

Grounding is an electrical connection with the earth, and bonding is an electrical connection with a conductor that is electrically connected with the earth. Both are very important as safety measures for static electricity. A conductor that is bonded to a grounded conductor can be seen as being grounded. Conductors with a leak resistance of 10^6 Ω or less can be seen as being electrostatically grounded.

Mechanism for Occurrences of Static Electricity and Series of Frictional Electrification

1) Mechanism of Occurrence

As is shown in **Fig. 2**, electrostatic charges occur through a movement of charges occurring at an interface when two different materials come in contact with each other, formation of a double electric layer, separation of charges occurring when the materials are separated and equal and opposite charges arising in the two in the proper amounts. The forms of static electricity can be classified according to the way electrification is handled as shown in **Fig. 3**. With the frictional charging in (a) in the figure, caution is required because of the risk of fire when a film is impregnated with an organic solvent or an organic solvent is being handled nearby. Another form of frictional charging that can be brought up is charging upon physical discharge through chute and powder transportation with gas stream. The streaming charging in (b) arises with transport in a pipe, but the probability of fire or explosion occurring within the pipe where the electrification occurs is generally low, and the problems usually occur with explosions in the gas phase part in the tank that is the destination of the fluid. Streaming charging also occurs in agitation tanks, but when slurries or two layer liquid with liquid arrangements are agitated in agitation tanks, caution is required because of the possibility of sedimentation electrification, which will be discussed later, when the agitation is stopped being much greater than streaming charging during agitation. Actual examples of the spray electrification in (c) that can be brought up include cleaning the inside of tanks using a shower ball, spray-jet cleaning using water or seawater, steam jets, high velocity gas jets containing drops or fumes from a venturi scrubber and leaks from flanges in high pressure pipes, but the point that must be kept

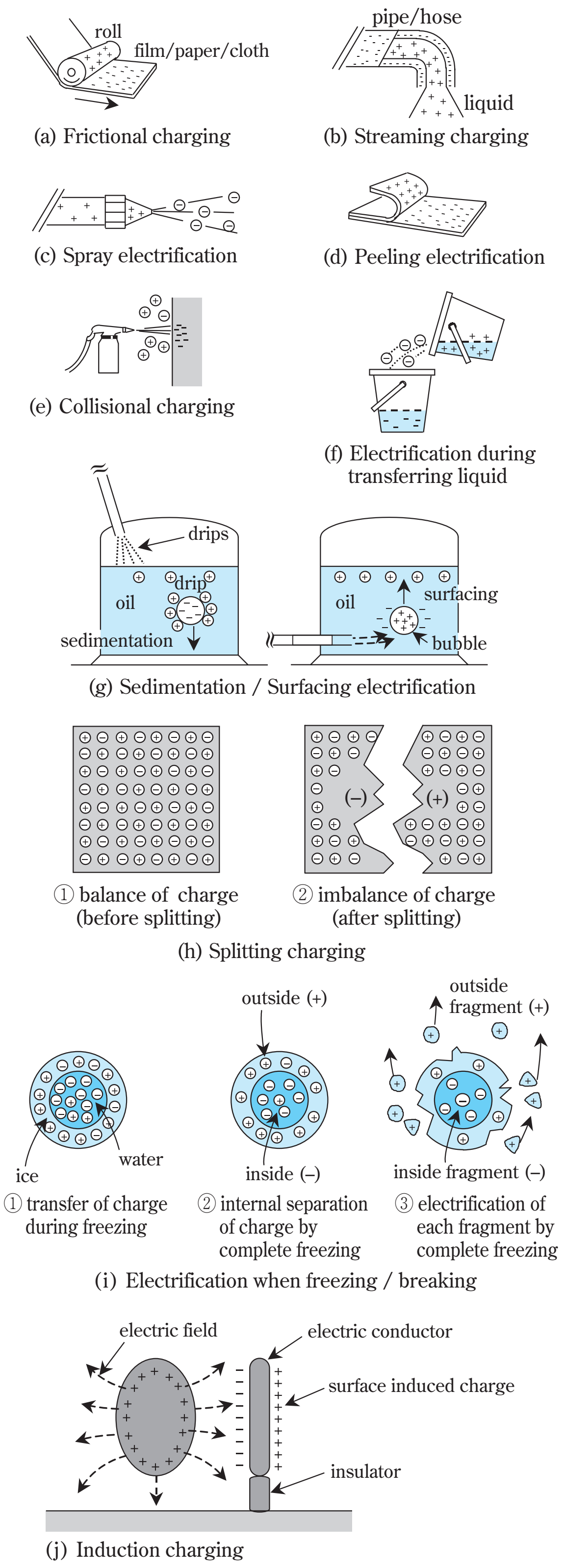


(a) Transfer of charge by contact

(b) Formation of electric double layer

(c) Electrification by separation

Fig. 2 Mechanism of electrostatic charge



(a) Frictional charging
(b) Streaming charging
(c) Spray electrification
(d) Peeling electrification
(e) Collisional charging
(f) Electrification during transferring liquid
(g) Sedimentation / Surfacing electrification
① balance of charge (before splitting)
② imbalance of charge (after splitting)
(h) Splitting charging
① transfer of charge during freezing
② internal separation of charge by complete freezing
③ electrification of each fragment by complete freezing
(i) Electrification when freezing / breaking
(j) Induction charging

Fig. 3 Example of electrostatic charge

in mind is that electricity passes through easily, and there is danger even with water and steam which are thought to be electrostatically safe. Besides the example shown in Fig. 3 (g) for sedimentation electrification, there is a danger of electrification with precipitation of solids or liquid-liquid separation arising when a slurry or liquid-liquid mixture is being agitated and the agitation stops. From the report of the Ministry of Internal Affairs and Communications, Fire and Disaster Management Agency it is highly possible that the fire in the naphtha tank that occurred at the Hokkaido oil plant due to the Tokachi earthquake occurring at sea in 2003 was caused by the chemical foam bubbles disappearing over time and sedimentation electrification with the water drops arising when water leaked precipitating in the naphtha.[4] In the induction charging in (j), static electricity is induced in an ungrounded metal vessel receiving a sample from sampling and tools or human bodies in the vicinity of a highly charged flexible container, and they may be strongly charged. In either case, caution is necessary because there can easily be a source of ignition when combustible solvents or gases are present in the vicinity.

2) Series of Frictional Electrification

We have already noted that electrostatic charging

metal (+)	fiber (+)	native material (+)	synthetic resin (+)
		asbestos	
		hair/fur	
		glass	
		mica	
	wool		
	nylon		
	rayon		
Pb			
	silk		
	cotton	raw cotton	
	hemp		
		wood	
		human skin	
	glass fiber		
Zn	acetate fiber		
Al			
		paper	
Cr			
			ebonite
Fe			
Cu			
Ni			
Au		rubber	polystyrene
	vinylon		
Pt			polypropylene
	polyester		
	acrylic fiber		
			polyethylene
	polyvinylidene chloride	celluloid	
		cellophane	
			vinyl chloride
			polytetrafluoroethylene
(–)	(–)	(–)	(–)

Fig. 4 Examples of series of frictional electrification

arises through the contact and separation of different materials, but there is affinity among materials that come in contact with each other in terms of the size of the charge, and these are brought together in series of frictional electrification. **Fig. 4** shows an example of series of frictional electrification.2) When two materials in an series of frictional electrification come in contact and are separated, the upper material is charged with a positive (+) charge and the lower one with a negative (–) charge. The charge increases with the distance between the vertical positions in the electrification series. The vertical relationships in the series of frictional electrification are effective over the types of materials. We should note here that is the positioning of polytetrafluoroethylene (Teflon) at the maximum for the negative polarity in the series of frictional electrification. In chemical plants that handle powders, Teflon is frequently applied to the insides of hoppers and chutes to improve the physical discharge, but since there are many cases where there is electrostatic hazard, so there must be a sufficient investigation into whether or not there is a hazard of dust explosion when this is used.

Discharge Types and Limits to Occurrences

Fires and explosions due to static electricity have electrostatic discharge phenomena as the source of ignition of combustible materials. The discharges take several forms, and understanding the characteristics of these is important in preventing fires and explosions due to static electricity. **Table 1** is a summary of the types and characteristics of discharges and the ignition hazards.1), 5) – 8)

Types of Electrostatic Accidents and Countermeasures

When disasters occur the losses are extensive. There is not only the obvious losses related to human life, those due to damage to facilities and those accompanying the stoppage of production activities, but also the loss of societal trust in the enterprise as in problems in responsibilities for supply, and problems of effects on the area surrounding the factory, so we must prevent these at all costs. Fires and explosions are oxidation combustion reactions, and it happens only when the three elements for combustion, 1 combustible materials, 2 oxidizer (air or oxygen) and 3 source of ignition are met. If one of the conditions is missing, fires and explosions will not happen. Therefore, in safety measures, we think in terms of eliminating these conditions. In the following we will give a description of accident phenomena according to type and will intro-

Table 1 Classifications of electrostatic discharge

Types of discharge	Characteristics	Hazards of ignition	Condition for discharge
Corona discharge	It can occur when an electrode with radius of curvature less than 5mm experiences a strong electric field.	not sufficiently energetic to ignite almost materials except sevral materials which has very small minimum ignition energy such as H_2, CS_2.	potential : more than several kilovolt
Brush discharge	It can occur between a conductor with radius of curvature in the range 5 to 50mm and either another conductor or a charged insulating surface.	sufficiently energetic to ignite gases and vapors and some dust cloud which has low minimum ignition energy (less than several mJ)	potential : more than dozens of kilovolt average of electric filed : more than 1×10^5 V/m
Cone discharge	It can occur along the conical surface of the powder heap during filling of a large silo with powder which has low conductivity.	sufficiently energetic to ignite gases and vapors and some dust cloud which has low minimum ignition energy (less than around 10 mJ)	diameter of powder : around 1~10mm
Lightning-like discharge	It can occur in a large container and a long spark jumps from the cloud to the grounded container wall.	sufficiently energetic to ignite gases and vapors and dust cloud	average of electric field : more than 2.7×10^5 V/m
Spark discharge	transitional discharge phenomenon which lead to arc or glow discharge.	sufficiently energetic to ignite gases and vapors and dust cloud	electric field : more than 3×10^6 V/m
Surface discharge	It can occur along the surface of thin insulating layer backed by a conductor.	sufficiently energetic to ignite gases and vapors and dust cloud	thickness of insulator : less than 8mm surface charge : more than $250\mu C/m^2$

duce safety measures from the standpoint of 1 eliminating combustible materials and 2 eliminating oxidizer, and finally we will introduce measures from the standpoint of eliminating the source of ignition.

1) Gas and Vapor Explosions

The minimum ignition energy for flammable vapors or gases is mostly around 0.2mJ, and since those are easily ignited by brush discharge, constructing ignition source countermeasures by grounding and the like alone is insufficient, and in safety engineering we must assume that sources of ignition are always present. Therefore, we must control the concentrations of combustible materials and oxidizer (a typical example being a nitrogen seal) and avoid entering the flammable region. The flammable region is often represented with a triangular diagram. As an example the flammable region of a methane-oxygen-nitrogen system is shown in a triangular diagram in **Fig. 5**.[9] Point A is 100% methane, and point B is 20% methane, 30% oxygen and 50% nitrogen. From this figure, we see that the lower flammable limit is basically fixed (approximately 5% methane) regardless of the oxygen and nitrogen concentrations, but the upper flammable limit is varies greatly according to the oxygen-nitrogen concentration. This applies in general to many gases. The direction of the arrow on line 1 is the line for dilution of methane with air, and point C signifies air itself. The methane concentration for intersection D of line 1 and the line for the upper flammable limit is the upper flammable limit of methane in air, and it is approximately 15%. The limiting oxygen concentration line is a line for the oxygen concentration that comes in contact with the flammable region lines, and it can be seen that the limiting oxygen concentration for methane is approximately 13%. If the oxygen concentration is less than 13%, we do not enter the flammable region no matter how the methane concentration changes, and if the methane concentration is less than 5%, we do not enter the flammable region even if, for example, the oxygen concentration increases. Moreover, we should take account of safety margin concerning concentration of flammable gases and oxygen for safety. A concentration of 1/4 the lower flammable limit of concentration for explosions is recommended for combustible gases. The U.S. National Fire Protection Association (NFPA) standards for oxygen concentration are given in **Table 2.**[10] Methane concentration of Point E exceeds upper flammable limit, and does not enter the flammable region, but when air leaks in to equipment or when gas with a composition equivalent to point E leaks into the air, it is diluted, and the path moves in the direction of the arrow on line 2 in the triangular diagram, entering the flammable region. The management with exceed upper flammable limit always accompanies this kind of hazard. Moreover, the explosive region is affected by temperature and pressure, so care is necessary in the handling of data.

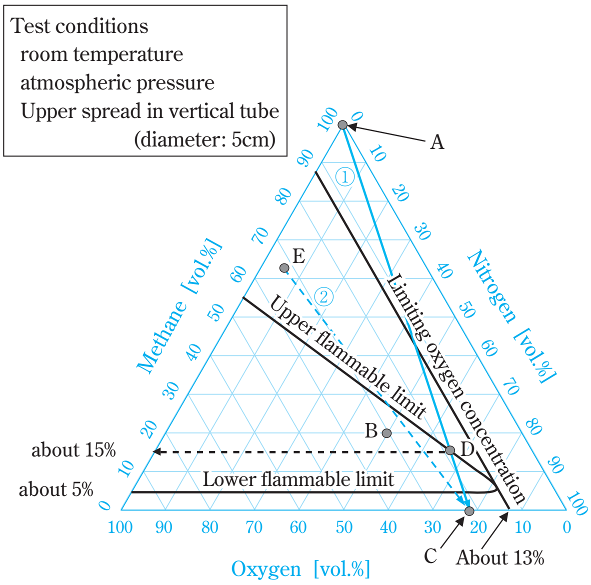


Fig. 5 Flammable limits of methane

Table 2 Safety margin of oxygen concentration

in case of continually monitoring of oxygen concentration	in case of non-continually monitoring of oxygen concentration
LOC ≥ 5% : LOC–2%	LOC ≥ 5% : LOC × 0.6%
LOC < 5% : LOC × 0.6%	LOC < 5% : LOC × 0.4%

LOC : Limiting oxygen concentration

2) Flash Fires with Flammable Liquids

Combustion of flammable liquids is not only contact combustion with the surface of the liquid, but also combustion of the gas phase in the vicinity of the liquid surface where the mixture of vaporized liquid and the atmosphere (normally air) enter the flammable region, and it can be assumed that combustion continues with a the repetition of combustion through the formation of a flammable atmosphere with the progress of new vaporization of the liquid due to the heat of combustion. Therefore, the minimum ignition energy for flammable liquids is the same as that for flammable gases, and we can assume that there is nothing strange about the existence of sources of ignition due to static electricity. However, when it is vapor from flammable liquids, it is different from methane and other gases that are normally in a gaseous state, and temperature at which the vapor pressure of a flammable liquid is equivalent to the lower flammable limit can be used as an index for safety management. The temperature at which the vapor pressure of a flammable liquid is equivalent to the lower flammable limit is defined as the lower flash point, and the temperature with equivalency to the upper flammable limit is defined as the upper flash point. At temperatures lower than the lower flash point, the vapor concentration in the gaseous phase is normally below the lower flammable, so there is no hazard of ignition. Moreover, we must be careful when there is a comparatively strong ignition source because there may be temperature rises in places even if the liquid temperature is below the flash point, causing flash fire. In addition, since the methods for measuring flash points determined by Japanese Industrial Standard (JIS) and used for the determination of class 4 hazardous materials in the Japanese Fire Service Law are not measurements under conditions reaching the ideal liquid-gas equilibrium, caution must be taken in that there is a difference from the true lower flash point. Here we will call the flash points obtained by JIS the JIS flash points. **Fig. 6** shows the difference between the lower flash point and the JIS closed cup flash point.[11] From this figure, it can be seen that it is necessary to have a safety margin of about 5°C with a JIS flash point of 20°C and a margin of about 10°C at one of 80°C. Moreover, it is essentially difficult to call maintaining a temperature above the upper flash point a safety measure. For example, it can be assumed that the vapor pressure of the gasoline in the gas tank of a car is higher than the upper flammable limit, so it is not in the flammable region, but care must be taken because the gasoline vapor is dispersed when filling and creates a flammable mixture in the vicinity, and there is a possibility that discharges from human bodies will ignite it. Moreover, the flash point of kerosene is approximately 40°C, and since the vapor pressure is lower than the lower flammable limit, it is possible to bring it into use in everyday life. Moreover, the explosion hazard increases when it coexists with combustible dust, and we must be careful that even if the concentration of vapor and dust are below their individual lower flammable/explosive limit, this is explosive. This point must be considered in operations where fine particles are introduced into organic solvents held at temperatures below the flash point.[12]

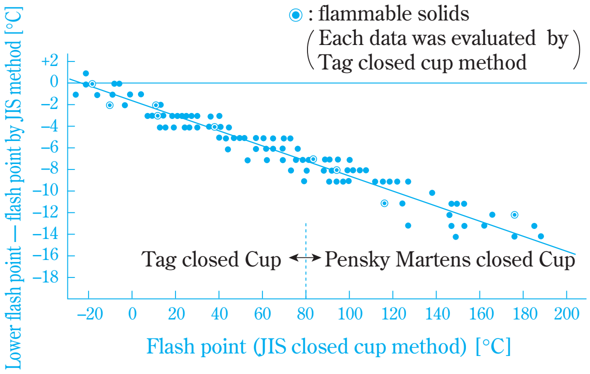


Fig. 6 Relations between flash point determined by the JIS closed cup and lower flash point

3) Dust Explosions

In general the minimum ignition energy for dust is on the order of 10mJ or higher, and it is one decimal place higher than the minimum ignition energy (around 0.2mJ) for common flammable gases and vapors. Therefore, there are cases where it can be handled in the air when grounding and other electrostatic measures are constructed. The minimum ignition energy is important as an index of whether fine powders should be handled in air. As shown in **Fig. 7**, the minimum ignition energy for dust explosions is found as the minimum value for energy when various changes are made to the ignition energy with a fixed dust concentration, at least three concentrations are used in operations finding the energies where dust explosions occur and energies where they do not occur and a convex curve is drawn under the boundary between explosions and no explosions. Moreover, dust explosions are greatly affected by the size of the particles, so evaluations with fine powders are necessary. Up to this point acquisition of data using particles filtered using a sieve with a No. 200 mesh with 75 µm openings has been carried out broadly, but the JIS Z8818 “Test method for minimum explosible concentration of combustible dusts” and the ISO6184/1 “Explosion protection systems-Part1: Determination of explosion indices of combustible dusts in air” specify the use of powders that have passed through 63 µm sieves.[13), 14)] Moreover, dust explosiveness is also affected by the shape of the particles, so when particle shape changes because of changes in production methods (changes in crystallization methods, for example), examinations of whether the minimum ignition energy must be re-evaluated or not should be made. With bag filters for collecting fine powders, comparatively large hoppers and silos and the like, it is common for to be prepared just in case and install explosion relief vent.[15]

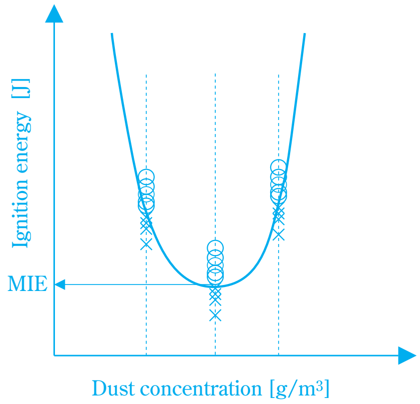


Fig. 7 Estimating method of minimum ignition energy

Moreover, with air transport and the like, it is sometimes effective to control the dust concentration below the lower explosive limit, but it is generally difficult to control dust concentration when fine particles are introduced in manual operations. Just as with flammable gases and vapors, the oxygen concentration index in Table 2 can be used as is for controlling oxygen concentration.

4) Mist Explosions[1, 16]

With mist explosions, it is often difficult to control the mist concentration, so controlling the oxygen concentration is the easiest and most certain safety measure. The minimum ignition energy for mist can be assumed to be similar to that for flammable gases and vapors from a safety engineering point of view, and we should think that it is not strange for electrostatic ignition sources to be present at all times. As is shown in Fig. 3 (c), static electricity is generated when the mist is produced. The periphery of the mist is blocked by highly insulating gases such as air, so the charge dispersion rate is slow. Therefore, even water and methanol, which have a volume resistivity of $10^8 \Omega \cdot$m or lower, are strongly electrified. In spray cleaning, pure water becomes more strongly electrified than highly insulating liquids such as toluene or hexane. Therefore, even when residual solvents are cleaned with a water spray, there is a possibility that the residual solvent vapor will be ignited by discharge from the charged water mist.

The explosion hazards with flammable liquid mists is not related to the flash point. The propagation mechanism for mist explosion can be thought of as being the same as that for dust explosions. If energy is given to the mist through a discharge, there are local rises in temperature, and the generation of dissociated gases due to vaporization or thermal decomposition is accelerated, locally forming flammable gas-air mixtures and burning. The heat radiating from the combustion heats the adjacent mist, and forms new flammable gas-air mixtures to burn, and these are propagated one after another. When the spaces in the mist become too distant (in other words, the mist concentration falls), the propagation cycle is interrupted, and the mist explosion stops. This limiting mist concentration is called the lower limit of mist explosion. **Fig. 8** is a summary of a mist explosion test apparatus developed by Sumitomo Chemical.[17]

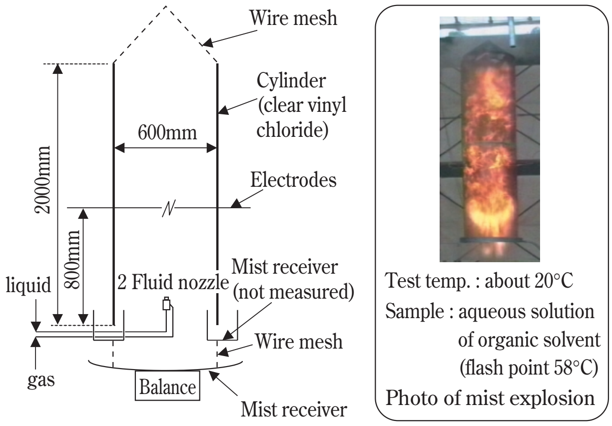


Fig. 8 Example of mist explosion and test apparatus

The main point in the evaluation of mist explosions is how a mist cloud that explodes easily is formed, and the two-fluid nozzle is superior in terms of this. The mist concentration measurements are measurements of the mass after the spray from the nozzle has stopped and the mist, which falls with gravity, has collected, and it is found by dividing by the volume of the suspension space. It is possible for mist explosions to occur when liquid in spray cleaning of tanks, liquid in mist separators or that being transported in pipes splashes, but the hazard of this is often missed, because the frequency of occurrence is lower than incidences of explosions of dust, gases and vapors and fires igniting in flammable liquids.

5) Fires of Dust Heap

Self-reactive substances such as explosives, and metallic powders of magnesium, aluminum, tantalum, zirconium and the like are often highly sensitive to electrical sparks, and it is possible for dust heap to be ignited by electrostatic discharge. The deactivation of self-reactive substances such as explosives using nitrogen seals may have no effect. Some metal dust heap have extremely low minimum ignition energy, but since they undergo oxidative combustion, deactivation with nitrogen is effective. See the references1) for details on the hazards of fire with dust heap.

Measures for Eliminating Ignition Sources

There are many types of measures for eliminating ignition sources, and their use must be divided according to the situation. In addition, since there are cases where an error in the countermeasure procedure means the effect will not be obtained and may have the reverse effect, so it is preferable that safety measures be determined in consultation with experts in static electricity. Given the limitations of this article, the following is a simple introduction, and one should see the references introduced at the end of this article and get guidance for the details.1), 2), 8), 10), 18)

1) Prevention of Electric Shock

There is not only the possibility of grave accidents occurring with falling or the tendency to fall due to receiving an electric shock, but also, in locations where flammable gases or explosive dust are present, there is the possibility that being shocked creates an ignition source that could cause a fire or explosion. Since the human body is a conductor, it can be assumed that the almost all of charge of human body is released when discharge happened. For example, if a human body with an electrostatic capacity of 100pF is electrified to 2kV, the stored energy is 0.2mJ, and this reaches the minimum ignition energy for common flammable gases and vapors. If the electrostatic measures taken for the human body are insufficient, this degree of electrification can easily arise. In terms of the electrification of the human body, the bottom of shoes that have insulating properties are electrified by friction electrification between the floor and the shoes when walking, and we can bring up cases where the body is electrified by taking on this electrostatic induction and cases where, when, in the operation of putting in or taking out a fine powder from a flexible container with insulating properties, the flexible container becomes strongly electrified and the human body takes on the electrostatic induction. Countermeasures we can mention are conductivity management of the floor and the wearing of antistatic shoes and antistatic work clothes. We will introduce an example of evaluating the electrification of the human body separately. Moreover, even if electrostatic countermeasures for the human body were perfect, it is still necessary to be careful because it is possible to receive an electric shock from other electrified conductors and insulators. If there is a location or operation where one receives even a little shock within a chemical plant, the cause must be pursued and suitable countermeasures constructed.

2) Prevention of Metal Electrification

Grounding or bonding is carried out. Care must be taken that bonding has no effect unless done with a grounded conductor.

3) Prevention of Electrification of Insulating Materials

Since this is difficult, it is smart to reduce the use in chemical plants as much as possible. When use is unavoidable, expert evaluations should be requested or nitrogen seals used.

4) Prevention of Electrification of Liquids During Pipe Transport

The initial flow limit (1m/sec or less) and flow limit for a static state should be adhered to.2) Relaxation pipe should be installed as necessary.

5) Handling of Flammable Liquids in Manual Operations

Electrostatic countermeasures for the human body should be worked out. After a container is transported, relaxation time should be taken. Grounding and bonding of metal containers should be done from before work starts to until it is completed. Care must be taken that drum transporters and other mobile equipment does not become floating conductors. Filter cloth with highly insulating properties should not be used in open systems. Funnels, pumps and the like with insulating properties should not be used in the handling of flammable liquids with conductivities of 10^8S/m or less. Other equipment matched to the work should be used correctly.

6) Hand Loading of Fine Powders[18)]

Caution should be taken about electrostatic charging when fine powders are dusted off of containers and bags. Deactivation measures should be used when fine powders are introduced into flammable liquids unless agreement can be obtained from safety experts. The possibilities for changing the order of loading (loading the fine powder first) should be investigated.

7) Use of Antistatic Agents

There are ones that are kneaded in and ones that are applied to insulating materials. There are antistatic agents that exhibit effects when added to liquids in amounts on the order of ppm. However, there is a need to examine problems with product quality.

8) Use of Static Charge Eliminators

Experts in the use of static charge eliminators should be consulted, and their use should be determined with sufficient examination of whether the static eliminator itself is a possible source of ignition.

Example of Evaluation

1) Evaluation of Electrostatic Hazard of Dust Cloud Using Electric Field Simulation

The hazard of ignition due to self-discharge from a dust cloud or mist cloud can be evaluated using electric field simulations. In electric field calculations, the electric potential and the electric field strength, which is its slope, can be found by solving Equation (1) shown in **Fig. 9**, and the possibilities of brush discharge or lightening-like discharge occurring can be examined. In addition, by finding the energy from Equation (2) and comparing it with the minimum ignition energy it is possible to estimate whether the discharge would have ignition capacity. The space charge density in Equation (1) is found from the product of the electrification charge and the dust concentration. For example, we can consider the powder dryer in **Fig. 10**. The space charge density is found at the point of measurement by using an aspiration type Faraday Cage as is shown in detail in **Fig. 11**.[19)] **Fig. 12** is an example of the calcu-

Poisson's equation

$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = -\frac{\rho}{\varepsilon} \qquad (1)$$

Energy calculation

$$U = \frac{1}{2} \int \varepsilon \cdot E^2 \, dV \qquad (2)$$

ϕ : Potential [V]
ρ : Space charge density [C/m^3]
ε : Dielectric constant [F/m]
U : Energy [J]
E : Electric field strength [V/m]

Fig. 9 Basic formula of electric fields

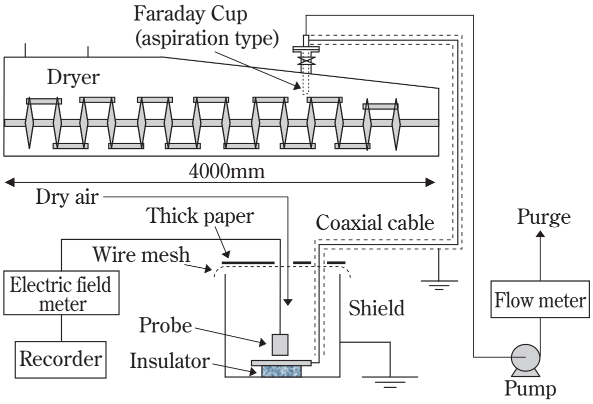


Fig. 10 Measurement of charged density of dust cloud

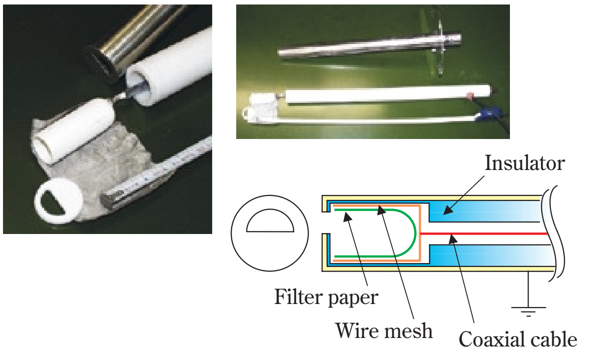


Fig. 11 Details of faraday cup (aspiration type)

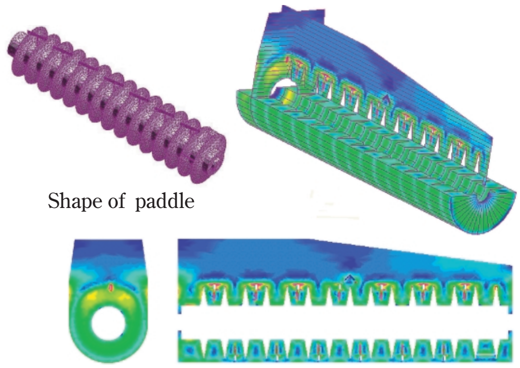


Fig. 12 Simulation results of electric field strength

lated results for electric field strength inside the dryer shown in Fig. 10 using ElecNet software from the Canadian company Infolytica Corp. (agent: Advanced Technologies Co., Ltd.). As the color moves from dark blue through yellow to red, the electric field strength becomes stronger. From the simulation, we can see that the electric field strength is high at the edges of the rotating paddles that play a role in crowding the powder. The form of discharge for which there is a possibility of igniting the dust cloud itself due to self-discharge from the dust cloud is a lightening-like discharge (see Table 1), and from the results of the simulation, it should be judged that there is a possibility of a lightening-like discharge in areas above the average electric field strength of 2.7 x 10^5 V/m, including areas of 3 x 10^6 V/m or more, which have an electric field strength that would locally break down the insulation of air. In the case of mist explosions, the minimum ignition energy is equivalent to that for flammable gases, and there is a possibility of ignition due to brush discharge. It can be assumed that brush discharge can occur in the area of 1.0 x 10^5 V/m or higher. If the latest computer simulations are used, it is possible to calculate the sum of the energy for the continuous area where this electric field strength exceeds a fixed threshold value, and by comparing this to the minimum ignition energy, it is possible to examine whether ignition would happen or not when an actual discharge occurs. This method has problems such as the determination of the space charge density being comparatively difficult and the effort for modeling of complex shapes, but it is an important evaluation method for safety. Furthermore, it does not end with calculations of electrostatic fields, and research into dynamic simulations of electric fields formed by charged particle groups has been introduced at academic society meetings; this is a field in which we can expect to see technical progress in the future.[20)]

2) Evaluation of Electrostatic Hazard of Human Body

As general measures for preventing human body electrification in chemical plants, 1 assurance of conductivity in the floor surfaces according to the substances handled and the working environment, 2 the wearing of antistatic shoes and 3 the wearing of antistatic work clothes are used. However, to work out measures for preventing exposure due to the handling of materials in filling and introduction work with fine powders that are strongly sensitivity causing, there are cases where a need arises for wearing special work clothes that are not normally used. In this instance, the work clothes must not simply be selected for the safety and hygiene of the human body, but also the fire and explosion prevention aspects must be considered in the determination of work clothes and working methods. Here we will take up an example of polypropylene working clothes and introduce the results of an examination of the relationship between the presence and absence of electrostatic countermeasures for the floors and human body and the electrostatic hazards. Polypropylene working clothes are actually sold, and the volume resistivity is 1.2 x 10^{15} $\Omega \cdot$m and the surface resistivity 2.1 x 10^{16} Ω, so it consists of highly insulating materials. As a result of measurements with a voltmeter (Kasuga Denki, Inc. KS-533) of the surface potential of polypropylene work clothes when there has been friction with a synthetic fiber vest several times in a test room with 50% humidity and a temperature of 20°C, where a conductive plate is laid out on urethane flooring material with a leak resistance of 9 x 10^7 Ω, and this is stood on with antistatic shoes and antistatic clothes and further when polypropylene work clothes are worn, it was found that the polypropylene work clothes had a surface potential of approximately 20 kV. This is a result that greatly exceeds the maximum value of 10 kV for the electrification index[2)] for insulators given in **Table 3**. In addition, the electric potential of the human body was measured in the same manner using a Fujimaru SR-111 Electrostatic Voltmeter, and the electrostatic capacity was measured using a Hewlett Packard 4332A LCR Meter; the results of calculations of the energy stored in the human body are given in **Table 4**. It was clear that in cases 3 – 6, the human body could store a level of energy that would be able to ignite common organic solvents. What should be noted here is that, as is demonstrated in case 6, even if polypropylene work clothes are not worn, safety is not secure if the shoes are not of an antistatic materi-

Table 3 Recommendations (potential of insulator)

Minimum ignition energy [mJ]	Indices of potential [kV]
< 0.1	< 1
0.1 ~ 1	< 5
1 ~ 10	< 10
> 10	< 10

Table 4 Results (human charge)

Items	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Floor	polyurethane floor + conductive grounded plate	polyurethane floor	polyurethane floor + conductive grounded plate	polyurethane floor + conductive grounded plate	polyurethane floor	polyurethane floor
Shoes	antistatic shoes	antistatic shoes	antistatic shoes	slippers	slippers	slippers
Clothes	antistatic working wares	antistatic working wares	polypropylene working wares	polypropylene working wares	polypropylene working wares	antistatic working wares
Maximum potential [V]	70	420	940	6100	7420	7970
Electrostatic capacity of human body [pF]	120	98	120	64	60	60
Energy accumulated to human body [mJ]	2.9E–04	8.6E–03	0.1	1.2	1.7	1.9

al, even if antistatic clothes is worn. Moreover, antistatic shoes and clothes may have a great difference concerning the ability for eliminating electrostatic hazards, so it is recommended that performance be confirmed on an individual wares when these are employed.

Conclusion

There have been sudden occurrences of electrostatic disasters at plants that have worked continuously for more than ten years without an accident and in operations that have been performed by hand by humans several thousand times without accidents, so past history gives no guarantee to the future.

It is important that we know electrostatic potential hazards of various operations by studying electrostatic prevention recommendations2) or case studies of electrostatic incident and each worker in chemical plant discovers electrostatic potential hazards which lurking in his operations. Next, the electrostatic hazards that are discovered should not be left as is, and the hazards should be reduced by referring to recommendations and handbooks and, when necessary, consulting experts about countermeasures. This is connected to improving safety records. We will be glad if this article is of some benefit to the reader in that sense.

References

1) THE INSTITUTE OF ELECTROSTATICS JAPAN: SHINBAN SEIDENKI HANDOBUKKU, (1998), OHMSHA, Ltd.
2) MINISTRY OF LABOUR RESEARCH INSTITUTE OF INDUSTRIAL SAFETY JAPZN: RIIS-TR-87-1 RECOMMENDED PRACTICE for Protection against Hazards arising out of Static Electricity in General Industries, (1988), TECHNOLOGY INSTITUTION OF INDUSTRIAL SAFETY
3) Heinz Haase Translated by M. Wald: Electrostatic Hazards Their Evaluation and control, (1977), VERLAG CHEMIE
4) SANGYOU TO HOAN-Dai 20 Kan Dai 24 Gou (Japanese), (2004)
5) S. Masuda: SAIKIN NO SEIDENKI KOUGAKU, (1974), THE HIGH PRESSURE GAS SAFETY INSTITUTE OF JAPAN
6) Jones T.B. and King J.L.: Powder Handling and Electrostatics: Understanding and Preventing Hazards, (1991), LEWIS
7) Glor M.: Electrostatic Hazards in Powder Handling, (1988), JHON WILEY & SONS INC.
8) NFPA: NFPA77 Recommended Practice on Static Electricity, (2000)
9) S. Yagyu: GASU OYOBI JYOKI NO BAKUHATUGENKAI, 50 (1977), JAPAN SOCIETY FOR SAFETY ENGINEERING
10) NFPA: NFPA69 Standard on Explosion Prevention Systems, 7 (1997)
11) S. Yagyu: Safety Document of the Research Institute of Industrial Safety RIIS-SD-86 Diagrams Related to Flashing Temperatures and Flammability Limits (1), (1986), JAPAN SOCIETY FOR SAFETY ENGINEERING
12) Rolf K. Eckhoff: Dust Explosions in the Process Industries, second edition, (1997), BUTTERWORTH HEINEMANN
13) JAPANESE STANDARDS ASSOCIATION, JIS Z 8818 Test method for minimum explosible concentration of combustible dusts, (2002)
14) ISO 6184/1 Explosion protection systems–Part1: Determination of explosion indices of combustible

dusts in air, (1985)
15) John Barton: DUST EXPLOSION PREVENTION AND PROTECTION, (2002), IChemE
16) Daniel A. Crowl and Joseph F. Louvar: Chemical Process Safety: Fundamentals with Applications, (1990), PRENTICE HALL
17) K. Ota et al.: DAI 34 KAI ANZEN KOUGAKU KENKYUU HAPPYOU KAI KOEN YOKOSHUU (JAPANESE), 59 (2001)
18) MINISTRY OF LABOUR RESEARCH INSTITUTE OF INDUSTRIAL SAFETY JAPZN: RIIS-TR-85-3 A supplement to “Recommended Practice for Protection against Hazards arising out of Static Electricity in General Industries” –Applications of Safety Measures to Selected Production Facilities, Work, etc.,(1986), TECHNOLOGY INSTITUTION OF INDUSTRIAL SAFETY
19) Y. Kumagae et al.: SUMITOMO KAGAKU,1990-II, **122** (1990)
20) A.Ohsawa, Powder Tech,**135–136**, 216 (2003)

PROFILE

Kiyoshi Ota

Sumitomo Chemical Co., Ltd.
Process & Production Technology Center
Research Associate