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Performance of Discharge in Two Phase Mixture of Air-droplet

Chen Zu-yun*(**)†, **Chen Liang***(**) **and Wu Chang-fu***(**)
*Faculty of Resource and Environmental Engineering, Jiangxi University of Science and Technology, Ganzhou, China
**Jiangxi Key Laboratory of Mining & Metallurgy Environmental Pollution Control, Ganzhou, China
†Corresponding author: Chen Zu-yun

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ABSTRACT

The influence performances in two phase mixture of air-droplet discharge are analysed in the paper based on the gaseous discharge unit process, and the mechanism in two phase mixture of air-droplet discharge is researched. The research obtains the result not only that the gas spray electrically charged effect is to cause the spatial free electron number to reduce greatly, while is to increase an amount of ions, and discharge phenomena is weakened, but the second voltage increased, intensity of electric field aggrandized too. But also that the free electronic collision frequency in two phase mixture of air-droplet increases every second, and that the collision ionization energy can be reduced, the adhesion coefficient of collision ionization increases, and that ion effective adhesion coefficient increases, and that water mist to the electronic affinity is higher and migration rate of iron is lower. So these factors contribute to the aerosol mixture discharged with a higher voltage, and it is favourable to improve dust performance.

INTRODUCTION

The discharge basic process in two phase mixture of air-droplet, whose discharge phenomena still occur in the gas phase, is similar to the process of discharge air, but its physical parameters are different because of the presence of water droplets, which can lead to a amount of different phenomenon unlike in the pure air. The influence performances in two phase mixture of air-droplet discharge are analysed in the paper based on the gaseous discharge unit process, and the mechanism in two phase mixture of air-droplet discharge is researched. These factors, on which not only the adhesion coefficient of collision ionization and the ion effective adhesion coefficient increase but also water mist to the electronic affinity is higher and migration rate of iron is lower, contributing to the aerosol mixture discharged with a higher voltage, and it is favourable to improve dust performance.

DISCHARGE OF FUNDAMENTAL PARTICLES IN TWO PHASE MIXTURE OF AIR-DROPLET

Both early space electron and the second electron of the discharge, of the occurrence and development process play a decisive role based on the discharge theory (Yang 1983). When fundamental particles in air water mixture discharge is taken into account (Kurnia 2014, Pak & Hu 2011), the existence of water droplets impact on the free electron production rate should be considered.

Cremation and corona discharges in air will produce a variety of discharge products, including high energy electrons, positive and negative ions, free radicals, ozone (O_3) and so on (Dey & Venkataraman 2012). In gas-water mixture, it contains lot of spray and water molecules in the air, producing a greater amount of active species in the discharge process (Lowke 2012), which makes it richer in species diversity than in the air. Some elementary particles produced in the gas-water mixture are as follows:

$$\begin{aligned} &H_2O \rightarrow OH^-(2.7) + e_{ap}^-(2.6) + H\ (0.6) \\ &+ H_2O_2(0.7) + H_3O^+(2.6) + H_2(0.45) \end{aligned} \quad ...(1)$$

Values in parentheses represent the value (G) (Michael 1992) of these particles, and it is defined as follows:

$$G = \frac{\text{variety of discharge products}}{\text{absorb100eV}}$$

Therefore, a lot of hydration of high energy electron e_{aq}^-, hydroxyl radicals OH^- and hydrogen radicals H^+, which are the most active components, in addition to a large amount of small water droplets and external tiny water H_2O, are produced from water droplets. The electronegativity of water molecule is strong, and easy to adsorb the electrons to form negative ion H_2O^-.

MAIN FACTORS INFLUENCING DISCHARGE DEVELOPMENT IN TWO PHASE MIXTURE OF AIR-DROPLET

Impact Ionization and Coefficient of Collision Ionization

Frequency of impact ionization: A piece of electron by speed of v collides with an atom or molecule, based on 'elastic collision' or 'non-elastic collision'. The electron collision may cause the atomic ionization or the drive, producing possibly new electron, ion and motivation atom. When the electron and the driving condition atom collides, the electronic kinetic energy may also pass to the atom to cause its ionization, but the driving condition atom also returns to the ground state, passing the excitation energy to the electron to cause its acceleration, and also including other neutral atoms. Moreover, after two drive condition atoms affect mutually, the atom possibly return to the ground state, giving the excitation energy to another atom, which causes the latter's ionization. This kind of ionization, which has the drive atom participation ionization, by the impact process, is called 'the second kind of ionization by impact'. Correspondingly, other several methods of ionization belong to 'the first kind of ionization by impact'. Certainly, the metastable state of the driving atom also possibly collides with other electron to produce the phenomenon of 'fractional ionization'.

When the movement speed of particles in the gas is greater than the movement speed of the gas molecules, the gas molecules can be considered as having no movement, and the mean free path of a particle with the collision cross-section is an inverse as type (1). The collision cross-section indicates an amount of collisions per unit length. While the gas pressure is high, and the gas member is quite dense, the mean free path will be shorter compared to the small density of gas, and the collision time in the unit length is also more.

$$\bar{\lambda} = \frac{1}{\pi N (r_1 + r_2)^2} = \frac{1}{\sigma N} \qquad ...(2)$$

Wherein: r_1-radius of the particle 1; r_2-radius of the particle 2; n-density of gas molecules; σN- total collision cross sections.

If the motion particle 1 is as the same kind of the gas molecule, $r_1=r_2=r$, formula (2) is as follows:

$$\bar{\lambda}_m = \frac{1}{4\pi N r^2} \qquad ...(3)$$

If the motion particle 1 is an electron, while the motion particle 2 is atom or molecule, namely $r_1 \ll r_2$, formula (2) becomes as follows:

$$\bar{\lambda}_e = \frac{1}{\pi N r_2^2} = 4\bar{\lambda}_m \qquad ...(4)$$

In the above assumptions the speed of particle 1 is faster than the speed of gas molecule 2. If the speed v_1 and v_2 of particles can be compared, then the relative velocity between them is $v = \sqrt{v_1^2 + v_2^2}$. Particle 2 can be seen as still not having movement, while the speed of particle 1 is not v_1 but v, then the mean free path of particle is calculated as follows:

$$\bar{\lambda} = \frac{v_1}{\pi N (r_1 + r_2)^2 \sqrt{v_1^2 + v_2^2}} \qquad ...(5)$$

In the same kind of gas, two kinds of particle are the same, namely the radius $r_1=r_2=r$, speed $v_1 = v_2$, the mean free path of particle is calculated as follows:

$$\bar{\lambda}_g = \frac{1}{4\sqrt{2}\pi N r_1^2} = \frac{1}{\sqrt{2}}\bar{\lambda}_m \qquad ...(6)$$

Since the electron is relatively small, the relationship between the mean free path of electron ($\bar{\lambda}_e$) with the mean free path of gas ($\bar{\lambda}_g$) is as follows:

$$\bar{\lambda}_e = 5.66\,\bar{\lambda}_m \qquad ...(7)$$

There is a relationship of both gas molecular density N, pressure P and temperature T as follows:

$$P = NkT \qquad ...(8)$$

Wherein, k is the Boltzmann constant, by type (8) and formula (6), the mean free path of particle is calculated as follows:

$$\bar{\lambda}_g = \frac{kT}{4\sqrt{2}\pi P r_1^2} \qquad ...(9)$$

Both the average mean free path of gas, average speed, and collision frequency f are listed in the Table 1 on the condition of T = 288 K, P = 760 torr. Because the reciprocal value of mean free path ($\bar{\lambda}$) is the number of collisions per unit length, $\bar{v}/\bar{\lambda} = f$ is an amount of collisions per second; $\bar{v}$ is the average speed of the random motion of molecule (Yang 1983).

An amount of collision with electron in two phase mixture of air-droplet per second is 138.76 times bigger than that of collision in the air from Table 1. Therefore, discharge in two phase mixture of air-droplet is more advantageous to charged particles.

Collision ionization energy: The exchange of energy between particles has a chance, even if an electronic kinetic energy already achieved the atom or molecule excitation energy or the ionizing energy. Each collision can, not only cause atomic excitation or ionization, some cause elastic collisions, some cause excitation or ionization, as shown in Fig. 1. Elastic collision, excitation collision and ionization collision process with different collision cross section, respectively are denoted by σ_{el}, σ_{ex}, σ_i. Total amount of collision with electron can be broken down as follows:

$$\sigma N = \sigma_{el} N + \sigma_{ex} N + \sigma_i N \qquad ...(10)$$

Therefore, ionization probability P_i is calculated as follows in the process of collision.

Table 1: Amount of collision.

Gas	Molecule weight	$\bar{\lambda}_g$ [10^{-8}m]	$\bar{v}$ [m/s]	Diameter [$\bar{A}$]	Number of collisions $\bar{v}/\bar{\lambda} = f$
O_2	32	6.79	437	3.61	64.36
N_2	28	6.28	467	3.75	74.36
H_2O	18	4.18	580	4.60	138.76

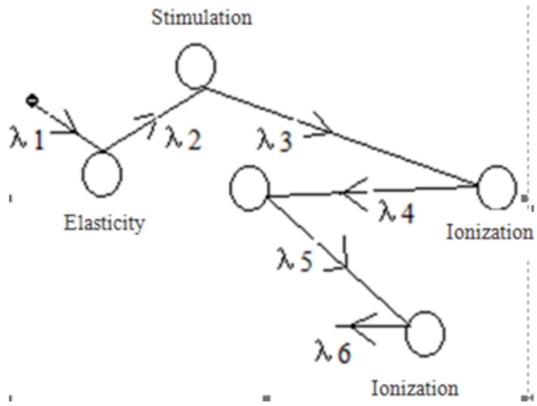

Fig. 1: Different types of collisions.

$$P_i = \frac{\sigma_i}{\sigma} = \frac{\bar{\lambda}}{\lambda_i} \quad ...(11)$$

The relatively larger size water droplets are filled in two phase mixture of air-droplet, and a large amount of water molecules is produced by volatilization. Since the collision cross section of water molecule (diameter of about 4.60Å) is greater than that of nitrogen and oxygen molecule (diameter is respectively 3.75Å, 3.61Å), collision probability of water molecule increases, as the water (H_2O) excitation energy (7.6eV) is less than oxygen excitation energy (7.9eV). The water ionization energy (12.59eV) is quite same with oxygen ionization energy (12.5eV), but is less than the ionization of nitrogen (15.6eV), so ionization of water molecules are more likely to happen, as given in Table 2. In this respect, an amount of free electrons, which is produced by electron ionization colliding with water molecules, increases more.

Impact ionization coefficient α: In the electric field, the electron by collision ionization per unit length along the field direction produces an amount of electrons called the electronic "impact ionization coefficient". In the gas discharge theory, the distribution function of both electron velocity and free travel are assumed in order to calculate formula of α, which is derived by the following two assumptions as follows:

1. The speed of ionization electron in the direction of the electric field begins to accelerate from zero until the collision with other ionization electron. The kinetic energy of electron from the electric field will be all over to transfer atom or molecule in each collision.
2. When the electron collides with other atom or molecule, if the electron kinetic energy is equal to or is greater than the ionizing energy of atom, the ionization by impact probability is equal to 1. As this, the ionization by impact coefficient α formula is calculated as follows (Smirnov 1982):

$$\frac{\alpha}{P} = Ae^{-BP/E} \quad ...(12)$$

Wherein, $A = \frac{1}{P\bar{\lambda}} = \frac{\sigma}{kT}$, $B = A\frac{W_i}{e} = \frac{W_i\sigma}{ekT}$

The A and B are constant in a certain range of E/P value, which can be measured by experiment. P-gas pressure; E-electric field intensity; λ-mean free path; σ-collision cross section; *k*-Boltzmann constant; T-temperature; W_i-ionizing energy of gas; particle, e-electron charge. In practical terms, the gas pressure P replaced the density of gas N.

The mean free path of molecule of water is $4.18\times10^{-8}m$, and is smaller than the mean free path of molecules of oxygen and nitrogen, respectively as $6.79\times10^{-8}m$ and 6.28×10^{-8} m, which lead the space of mean free path of electrons to reduce, which also make the impact ionization coefficient to increase (Cui Lin et al. 2012). The water molecules in two phase mixture of air-droplet increase so that both the collision probability and the ionization coefficient α are aggrandized. So the corona charged dust in two phase mixture of air-droplet is more effective than corona charged dust in the air.

Adhesion/Separation Process and Effective Adhesion Coefficient

The negative ion formation is of great significance for the gas discharge. In these gases, atoms or molecules readily attach to electrons to form negative ions, which can reduce the electrons in the gas, thus enhance the disruptive strength of gas.

Several forms of attachment and separation: The formation of negative ion is of great significance for the gas dis-

Table 2: Several substances excitation energy and ionization energy (Yang Jin-ji. 1983).

Gas	Excitation energy We [eV]	Ionization energy Wi [eV]	Second ionization energy Wi [eV]	Third ionization energy Wi [eV]
Oxygen O_2	7.9	12.5		
O	19.7, 9.15	13.61	35	55
Nitrogen N_2	6.3	15.6		
N	2.38, 10.33	14.54	29.5	47
Water H_2O	7.6	12.59		

Table 3: Charged electrically gaseous ion transport ratio in 0°C and 1.013×105Pa (i.e. 1atm) (Kulikovsky 1997).

Gas	Transport ratio k ($m^2.s^{-1}.V^{-1}$)×10^{-4}		Gas	Transport ratio k ($m^2.s^{-1}.V^{-1}$)×10^{-4}	
	K(-)	K(+)		K(-)	K(+)
He	-*	10.4	C_2H_2	0.83	0.78
Ne	-	4.2	C_2H_5OH	0.37	0.36
Kr	-	0.9	CO	1.14	1.10
Xe	-	0.6	CO_2	0.98	0.84
Air (dry)	2.1	1.36	HCl	0.62	0.53
Air (very dry)	2.5	1.8	H_2O	0.95	1.1
N_2	-	1.8	H_2S	0.65	0.62
O_2	2.6	1.8	NH_3	0.66	0.56
H_2	-	2.2	N_2O	0.9	0.82
Cl_2		0.74	SO_2	0.41	0.41
CCl_4		0.30	SF_6	0.57	

Note: *denotes no electronic attachment in pure gas.

charge, negative ion forms and disappears by some of the following ways:

1. The negative ion forms to emit photon, and this kind of mechanism is called "radiation adhesion".

   $e + A \rightarrow A^- + hv$ ...(13)

   The reverse process is ion absorbs radiant energy, and the electron of combination is released, called photo-detachment.

2. During the course of collision, if there exists third particle B, and the electron is attached to the atom releasing the energy which may also be absorbed by the particle B, to become its kinetic energy.

   $e + A + B \rightarrow A^- + (B + \text{kinetic energy})$

3. When the electron collides with the molecules (XY), the unnecessary energy divides the molecules into a neutral atom and an ion, so this is called decomposition attachment. The reverse process is called the associative detachment.

   $e + XY \rightarrow (XY)^{-*} \rightarrow X^- + Y$ ...(14)

4. When an electron impacts a molecule (XY), it may cause vibration between atoms in the molecule. When the molecule is collided with another particle A, this vibration excitation energy can be transformed into potential energy W_p or kinetic energy W_k of particle A.

   $e + XY \rightarrow (XY)^-$ ...(15)

   $XY^{-*} + A \rightarrow XY^- + A + W_p + W_k$ ...(16)

5. The electron and the molecular collision can also cause the molecular fission, and the process is reversible.

   $e + XY \rightarrow X^+ + Y^- + e$ ...(17)

Effective adhesion coefficient η: The effective adhesion coefficient η is considered the final result of attachment and separation of two factors. On one hand, the effective adhesion coefficient η is closely related to the electric field strength, and its relationship with the local electric field is similar to the relationship between the impact ionization coefficient α with electric field. On the other hand, the water molecule's electronegativity is 7.64, and electronegativity of oxygen and nitrogen are respectively 6.88 and 6.08, based on Pauling scale calculation (Smirnov 1982). Moreover, the water molecules easily absorb negative particles, in order to form the composite ion, such as $A^-.(H_2O)_n{}^-H_2O$ (Cui Lin et al. 2012). It can be seen that water molecules absorb electrons in two phase mixture of air-droplet more than the air do. Kuffel found through experiments, that the value of η/N increased numerical ranges from 1.7 to 7, when the value of E/N is between 0.5×10^{-15} V.cm^2 and 1.0×10^{-15} V.cm^2 in the 2.8% of water in the humid air. Prasad and Craggs also reported similar results (Gallagher et al. 1983). Gas-water mixture has a large amount of water molecules and small water droplets, and air humidity is saturated, and droplets of water also charged for electronic effects, therefore, the highly effective adhesion coefficient is higher than in dry air.

Compound Process and Recombination Coefficient

Composite form: Composite is the opposite process of ionization, and electron and ion in the compound probability per unit volume of the number of free electrons and positive ions per unit volume is proportional to an amount of both the complex process of positive and negative ions and neutral molecules and ion concentration. When negative ions and positive ions are similar to quality, speed, etc., at the time of collision, ions can lose most of the kinetic energy, so that the ion velocity after the collision became very low, positive and negative ions in contact for a long time, and chance of cationic and anionic compound will be much higher.

Ion recombination coefficient λ: The ion recombination coefficient λ is always much larger than the electron recombination coefficient β, when the value of ion recombination coefficient λ is generally measured about $10^{-6}\ cm^3.s^{-1}$, the value of electron recombination coefficient β is 10^{-10} -10^{-8} $cm^3.s^{-1}$ (Zhao Feng &Wang Xu 2012, Steinle et al. 1999).

Because gas water mixture discharge can produce more species than air discharge, including more positive, negative ions and hydrated electron, both ion recombination coefficient and electron recombination coefficient are bound to increase.

Charged Particle Migration

In two phase mixture of air-droplet discharge, the stable ion of space at both poles is required to provide electrostatic charge source, in order to capture the dust. In the case of positive corona, these space ions are composed of the positive ions moving toward cathode by positive corona generated (Wang Junfeng et al. 2015, Xu et al. 2015). While in the case of negative corona, these space ions are composed of the free electron or negative ions moving towards anode by negative corona generated in the neutral gas molecules or atoms. Due to the free electron migration rate is much higher (about 1000 times higher) than the gas ions, if the free electron is not attached to the gas molecule, it flows quickly to the electrodes, so the space charge stability between the poles can not be formed. Obviously to the negative electronics corona, the formation of negative ions is significant impact on corona discharge process.

Negative ion formation depends on the gas molecules or atoms trapped electron affinity ability. In spray charge precipitator, corona current is mainly affected by the movement of free electrons and negative ions, and gas molecules have different electron affinity ability.

So when the gas whose electron affinity ability is high, whose rate of charged particle migration is low, is added suitably in order to have even higher voltage charge, namely working under a stronger electric field. There are a large amount of water molecules and spray in two phase mixture of air-droplet discharge, and the air humidity is saturated. The electron affinity ability of water mist is high, and the rate of charged particle migration of water mist is low, so the gas water mixture discharge has a higher voltage, so that it is advantageous to improve the dust removal performance.

ELECTRICAL CONDUCTIVITY OF LIQUID

Electrical conductivity of the liquid medium is defined the current through liquid in electrostatic field, and the size to conductivity Y (s/m) or volume resistivity l/Y (Ω.m) is expressed. The current carrier within liquid can move freely, and form current by moving along the direction of electric field under the action of electric field. Determining the strength of conductivity of liquid micro-size parameter is both carrier concentration and rate mobility. The current carrier of liquid is mainly ions, including intrinsic ion and impurity ions. The intrinsic ion is produced by the basic molecular dissociation liquid itself, and evidently exist in the ion in strong polar liquid medium (such as organic acids, alcohols, phenolic esters). Impurity ion is made up of foreign matter (such as acids, alkalis, organic salts) or liquid basic molecular dissociation and aging generating ions. Electrical conductivity is smaller than pure liquids, and electrical conductivity of non-polar liquids is generally smaller than those of polar media. Several different rates of medium resistivity are listed in Table 4.

CONCLUSION

In two phase mixture of air-droplet, the presence of water droplets strongly distorts the electric field in the region to strengthen the local electric field, and electron impact ionization and attachment processes have been strengthened, the amount of electrons and ions in space led to greatly increase. So this has further increased the electronic collision ionization.

1. The electronegativity of water molecules is strong, and easy to adsorb the electron to form negative ion H_2O^-. The amount of collisions in two phase mixture of air-droplet per second is bigger than that of collisions in the air. Therefore, discharge in two phase mixture of air-droplet is more advantageous to charged particles.
2. The water molecules in two phase mixture of air-droplet increase so that both the collision probability and the ionization coefficient α aggrandize. So the corona charged dust in two phase mixture of air-droplet is more

Table 4: Different medium relative dielectric constant ε_r and rate of volume resistivity l/Y(Ω.m).

Dielectric apellation	Medium relative dielectric constant ε_r	Rate of volume resistivity l/Y(Ω.m)
Air	1.00059	10^{16}
Petrol, kerosene	1.9-2.0	10^{10}-10^{12}
Heptane	2.0	4.9×10^{11}
Alcohol	7	4.9×10^{5}
Water	81	2×10^{3}
Transformer oil	2.1	10^{10}-10^{12}

effective than corona charged dust in the air.

3. Gas-water mixture has a large amount of water molecules and small water droplets, and air humidity is saturated, and droplets of water also charged for electronic effects, therefore, highly effective adhesion coefficient is higher than in dry air. Because gas water mixture discharge can produce more species than air discharge, including more positive, negative ions and hydrated electrons, both ion recombination coefficient and electron recombination coefficient are bound to increase.
4. The electron affinity ability of water mist is high, and the rate of charged particle migration of water mist is low, so the gas water mixture discharge has a higher voltage, so that it is advantageous to improve the dust removal performance.

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