

CHAPTER 1

INTRODUCTION

This chapter serves as an introduction to the thesis and the objective of the current work. The first section of the chapter presents the current state and significance of knowledge on submicron particle collection related problems. The second section presents a literature review of the existing techniques for enhancement of electrostatic precipitator (ESP) for submicron particle collection including enhancement of submicron particle charging, enhancement of submicron particle agglomeration, and non-thermal plasma (NTP) technique for submicron particle control. The aims, benefits, and scope of the current study are also presented in the last section of this chapter

1.1 Statement and Significance of the Problem

In recent years, special environmental concern is directed towards controlling the particles emission that derived chiefly from combustion processes in transportation, manufacturing, power generation. The air polluted by submicron particle have more effects on the human health, global climate, and various industry processes that need high air quality such as food, pharmaceutical and medical, electronic and semiconductor industries. The submicron particles have been proved to very harmful to the human health (Pope 2000). Because of their high number density, high superficial area, thus favoring the adsorption of toxic substances and ability to penetrate deep into the lung, thus these are increasing the potential harmful effects to the human organism and associated to asthma, intra respiratory. Therefore, there is a need to develop efficient and economical techniques to control these emissions.

One of the most efficient devices for controlling the particle emission is the ESPs. They have been widely used in separating particulates from exhaust gas streams. They are characterized by high overall mass collection efficiency (above

90%) with low-pressure drop and low electrical power consumptions. However, the particulate collection efficiencies in term of number of density for the submicron particles are often observed to be less than 50% (T. Ito *et al.* 1995), since most of the submicron particles escape from the ESP (M. Mohr *et al.* 1996). The low collection efficiency of ESPs is due to the difficulty in charging the particles having diameters less than 1 μm . Therefore, enhancement the collection efficiency of conventional ESPs for these submicron particles is needed.

There are many techniques to enhance the collection of submicron particles such as ultrasonic agglomeration of the fine particles (H. Anyoma *et al.* 1993) and electrostatic agglomerates (J. Kildeso *et al.* 1995); chemical agglomeration of the fine particles by conditioning agents such as ammonia, ethanol amines, etc.(A. Teller and J. Qimby 1991); thermal precipitations(J. S. Chang 1986); electron particle charging(J. S. Chang *et al.* 1992); and wet electrostatic precipitation(A. Zukeran *et al.* 1996). Recent studies on the short pulse corona energization to generate NTP have been reported. With this technique, an ESP could generate much higher electron density than that of the DC energization and, hence, enhance particle charging due to much larger mobility of electrons. As a result, it improves the collection efficiency of submicron particles. Fortunately, the NTP region always propagates in a direction across the air stream and bipolar charging of particles occurs. Therefore, the submicron particles can agglomerate to large size which can be captured easily.

NTP techniques have current been investigated intensively as a promising technology of diesel engine after treatment to abate particular matter (PM), HC and NO_x . NTP technology mainly includes surface discharge, electron beam irradiation, pulsed corona discharge (PCD) and dielectric barrier discharge (DBD). Numerous experiments have been carried out to reduce PM, HC and NO_x from diesel exhaust emissions using these approaches. Yao *et al.*(2004) reported that an uneven discharge reactor, combining DBD with PCD during discharges, could achieve PM removal efficiency of 67 % at 300 W, and the energy efficiency was typically in a range of 3-16 g/kWh, and the energy density of 2-16J/L. Willems *et al.* (2003) evaluated the PM reduction in packed-bed plasma system with the experimental results indicating that 90% removal efficiency based on smoke measurements was determined at energy density 25 J/L for relatively small velocities. Besides, Sato *et al.* (2005) developed a

PM electrostatic precipitator, integrating a duct pocket with DBD device installed in the downstream. Carbon particles were oxidized by the barrier discharges, and pulled into the high electric field region touching to the mesh of the dust pocket. After the operating the experiment for long period up to 180 min, the collection efficiency could be kept at almost the same level of 99 %. Anyhow, there were some drawbacks. This technique was difficult to apply in the large scale and needed a high maintenance with high energy consumption and high investment cost.

The objective of this thesis is to provide the experimental study on the enhancement of ESP for submicron particle collection using non-thermal technique. This study also investigates the parameters affecting on the submicron particle agglomeration and particle collection efficiency such as gas flow velocity, electric field strength, particle density, and gas temperature.

1.2 Literature Reviews

1.2.1 Enhancement of Submicron Particles Charging

Charging process is an important step influencing the collection efficiency of submicron particles. Two important charging processes are field charging and diffusion charging. The field charging is known to be effective for the large particles. On the other hand, diffusion charging becomes dominant as the size decreases. The valley area where the two charge mechanisms are weak is usually found around the particle size of 0.2 μm . The electron charging, photo-charging including UV and soft X-ray irradiation and pulsed charging are proposed and demonstrated to enhance ion concentration on the submicron particles then collection efficiency of submicron particles could be increased.

K.H. Yoo *et al.* (1997) experimentally studied the charging and collection of submicron particles in two-stage parallel-plate ESP. As shown in Figure 1.1, the experimental setup consisted of five components: a clean wind tunnel, a submicron particle generation system, an aerosol sampling and transport system, measurement system for a submicron particle number concentration, and a pilot-scale two-stage parallel-plate ESP. Experimental collection efficiency data were obtained with geometric mean diameter (GMD) of 0.03-0.2 μm and geometric standard

diameter (GSD) about 1.67 for air velocity between 1.9 and 4.1 m/s. The experimental data were then compared with the results of a numerical collection efficiency model which considered charging rate equations, particle equations of motion, and collection performance. The comparison showed good agreement. It was confirmed from the comparison that the partial charging regime, where a portion of incoming particles was not charged, existed when the particle size range was below about $0.03 \mu\text{m}$. This partial charging effect caused a significant decrease in the ESP efficiency.

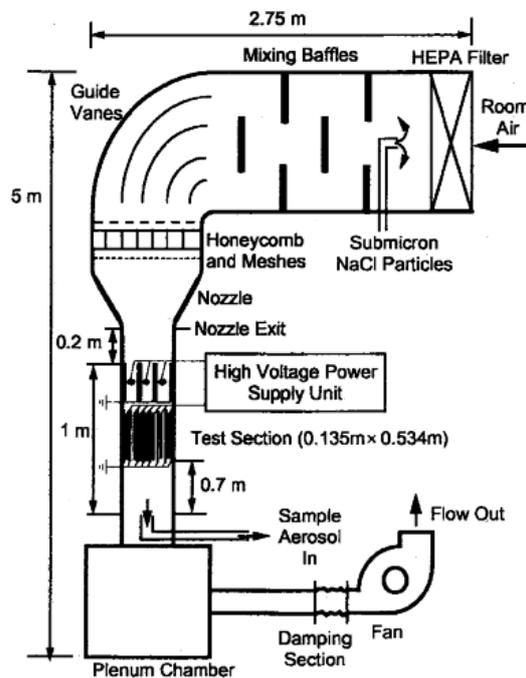


Figure 1.1 Schematic diagram of the clean wind tunnel for ESP particle size efficiency test

(K. H. Yoo *et al.* 1997).

A. Zukeran *et al.* (1999) experimentally studied the ultra fine particle collection efficiency of ESP under DC and pulse operating modes. The ESP consisted of three set wire-plate type electrodes. A schematic of two-section ESP is shown in Figure 1.2, where the first section was a two-wire-type and second section was a single-wire-type ESP, respectively. The diameter of corona wire was 1.5 mm. The width between plates was 50 mm, the length of the first section was 200 mm, and the length of the second section was 100 mm. Experiments were conducted for the

dust loading of 10^9 to 6×10^{10} particles/m³ or 5-155 mg/m³, the size distribution of particles of around 0.2-0.3 μm , the flue gas temperature of 23 °C to 100 °C, the wire-plate applied voltage of 0 to -25 kV, and of 0 to -30 kV for pulse operating. The flue gas flow rate was 12 Nm³/h. For the ESP under DC operation modes, the experimental results showed that the collection efficiency for DC applied voltage decreased with increasing dust loading when particle density was larger than 2.5×10^{10} particles/m³ due to inefficient collection of ultrafine particles. However, under the pulse operating mode without DC bias, high particle collection for ultrafine particles was obtained due to the enhancement of particle charging by electrons.

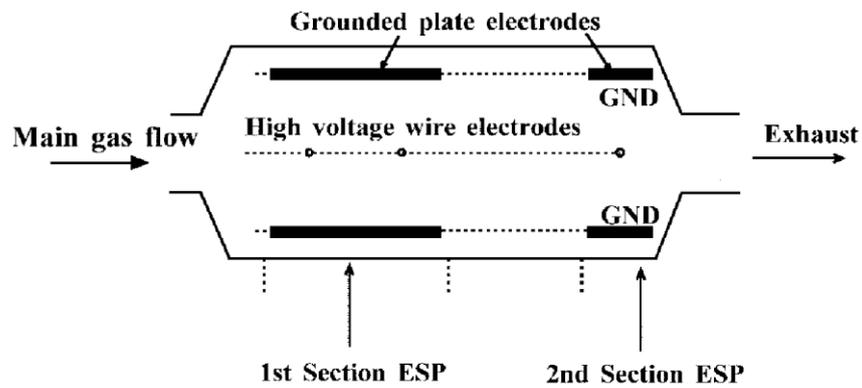


Figure 1.2 Schematic of ESP electrode arrangements (GND: grounded electrodes)

(A. Zukeran *et al.* 1999).

P. Kulkarni *et al.* (2002) experimentally studied the fine particles charging in unipolar coronas irradiated by soft X-rays (3.5-9.5 keV, $\lambda = 0.13$ -0.41 nm). The experimental setup used for measure efficiency of ESP under tested with and without X-ray irradiation was shown in Figure 1.3. The corona inception voltage in presence and absence of X-ray irradiation and to estimate the ion concentrations were examined by the voltage-current characteristics. The capture characteristics of synthesized particles: iron oxide, sodium chloride, silica and titanium dioxide, were established in coronas under with and without X-ray irradiation. Enhanced charging of ultrafine particles in coronas with soft X-ray irradiation was observed in conjunction. Charging efficiencies by a positive corona with X-ray resulted in highest,

followed by a negative corona with X-ray, X-ray only, negative corona only and finally positive corona only. Theory of particle charging available in the literature was used to qualitatively explain the observed trends.

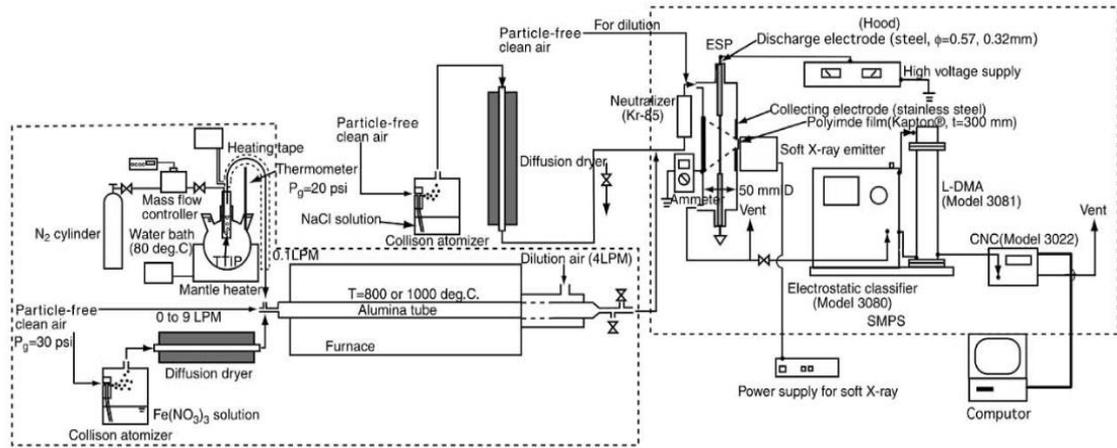


Figure 1.3 Schematic diagram of the experimental setup used to measure particle capture efficiency of ESP with and without X-ray irradiation

(P. Kulkarni *et al.* 2002).

Xu Dexuan *et al.* (2002) experimentally studied the positive short-pulse corona discharge charging of aerosol particles. The experimental results showed that the number of negatively charged particles was more than that of positively charged ones could reach 2:1. The theoretical analysis demonstrated the positive short-pulse corona discharges including both steamer and corona discharges. The positive steamer discharges consisted of many NTP leads (steamers) of the branch type, which had high ionized ability and propagated rapidly from anode to cathode with the aid of ionization by photon. The steamer discharges were at the pre-breakdown stage. The positive corona discharges had a thin ionization layer around the anode and most of the inter-electrode space was a positive-ion-charging region.

J. H. Ahn *et al.* (2003) investigated the charging characteristics of submicron particles. Figure 1.4 shows a schematic diagram of the experimental setup.

Particle charging and collection efficiency were measured with electrometer; condensation nuclei counter (CNC) and scanning mobility particle sizer (SMPS). Electro spray (E/S) is a process that relies on electrostatic force to break the liquid into charged droplets. During this process, many highly charged small droplets or ions are attached to the foreign particles and eventually charge the particles. This process is distinct from corona discharge. The difference in charging rate between corona discharge and E/S results in the difference in the collection efficiency for submicron particles. The control of particles by charging and collection with E/S and corona discharge was investigated experimentally. The result showed that the collection efficiency of E/S electrostatic precipitator system was higher than 99.9% for particles with a geometric mean diameter (GMD) of 5-100 nm at the mean face velocity of 0.5 m/s and 1 m/s.

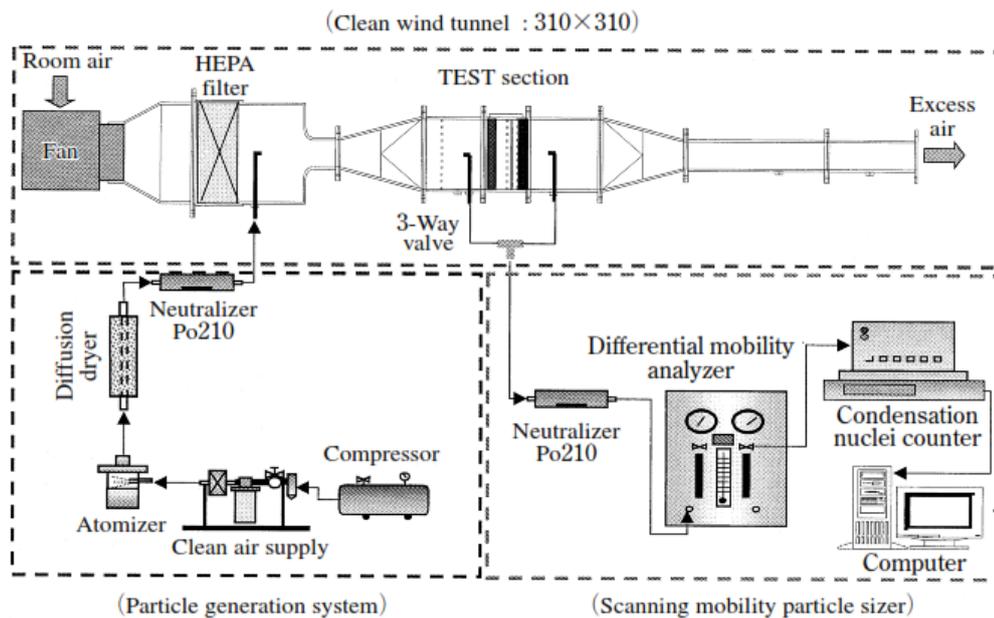


Figure 1.4 Schematic diagram of experimental setup for performance ESP (J.H. Ahn *et al.* 2003).

F. Xu *et al.* (2009) investigated experimentally the positive pulsed ESP to enhance particle charging and improve collection efficiency. In Figure 1.5, a laboratory-scale pulsed ESP with wire-plate electrode configuration was established to investigate the particle charging and penetration efficiency under controlled

operating conditions of different applied impulse peak voltages, impulse frequencies, dust loadings and residence times. The results showed that most particles larger than $0.2\ \mu\text{m}$ were negatively charged, while most particles smaller than $0.2\ \mu\text{m}$ were positively charged. For a given operating condition, the particle penetration efficiency curve had the highest penetration efficiency for particles with a diameter near $0.2\ \mu\text{m}$, and there always was a negative correlation between the particle penetration efficiency and the average number of charges per particle. Under the same operating conditions, the particle penetration efficiency decreased with increasing impulse peak voltage and impulse frequency, but increased as the dust loading increased. The result also showed that the residence time of 4 s was optimum for particle charging and collection. Over 90 % of $\text{PM}_{2.5}$ numbers could be collected in pulsed ESP.

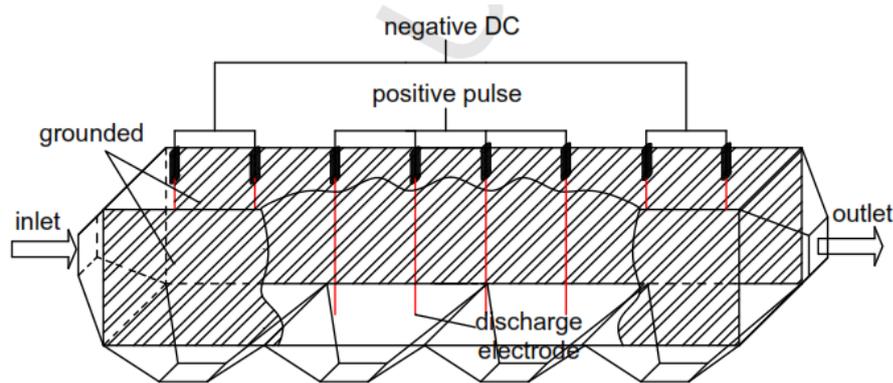


Figure 1.5 A laboratory-scale pulsed ESP with wire-plate electrode configuration for Experimental investigation on charging characteristics and penetration efficiency of $\text{PM}_{2.5}$ emitted from coal combustion enhanced by positive corona pulsed ESP (F. Xu *et al.* 2009).

W. Y. Lin *et al.* (2011) experimentally studied the separation characteristics of submicron particles in ESP with alternating electric field corona charger. Experiments were carried out to investigate filtration characteristics of an ESP with alternating and direct electric field corona charger. Potassium Sodium Tartrate Tetra hydrate as the material was used to generate poly disperse submicron

aerosols by using Constant Output Atomizer. The experimental scheme is shown in Figure 1.6. It was found that the aerosol penetration through the ESP decreased as the applied voltage increased. The maximum collection efficiency of either alternating or direct electric field was more than 98%, though the applied voltage of alternating electric field was higher than that of direct electric field. However, from the viewpoint of power consumption, the direct electric field had higher power consumption rate than that of alternating electric field at similar collection efficiency. When the penetration of particles (about 0.2 μm) through the ESP was about 4%, the power consumption of alternating and direct electric field were 16 watt and 18 watt, respectively. Hence the separation quality of alternating electric field was better than that of direct electric field. Moreover, considerably lower ozone concentration was found in alternating electric field ESP, compared to direct electric field.

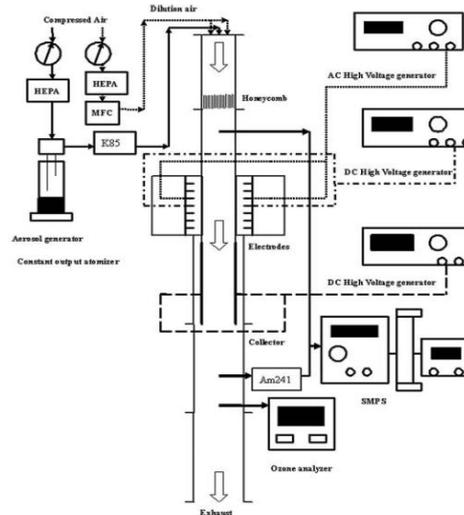


Figure 1.6 Experimental set up for studied the separation characteristics of submicron particles in ESP with alternating electric field corona charger

(W.Y. Lin *et al.* 2011).

1.2.2 Submicron Particle Agglomeration Enhancements

One of the most effective and economical method for improving the collection efficiency of ESP is particle agglomeration. The particle agglomeration is a process that the submicron particles are adhered to form a larger one which can be detected and removed easily. Many agglomeration techniques have been proposed

such as: (i) injection of chemicals into gas streams to increase agglomeration of submicron particles, (ii) use of laminar flow precipitators to promote surface agglomeration of submicron particles, (iii) acoustic agitation of dust particles suspended in a gas to increase impingement and create agglomeration, (iv) AC or DC agitation of charged particles suspended in a gas to mixing and create agglomeration, and (v) bipolar charging of particles in a gas stream for electrostatic agglomeration.

T. Watanabe *et al.* (1995) designed and experimentally studied the new types of the ESP for submicron particles collection in exhausted gas from a fine grained coal-burning boiler. This ESP combined with an electrostatic agglomeration apparatus (EAA) as shown in Figure 1.7. A measured weight percentage of submicron-sized particles under $1\ \mu\text{m}$ decreased 20% and a mean diameter of aerosol particles increased to four times of that at the inlet when an EAA was used. The designed ESP was expected to increase to collection efficiency from 95 to 98% in the particle size range of $0.03\text{-}12\ \mu\text{m}$.

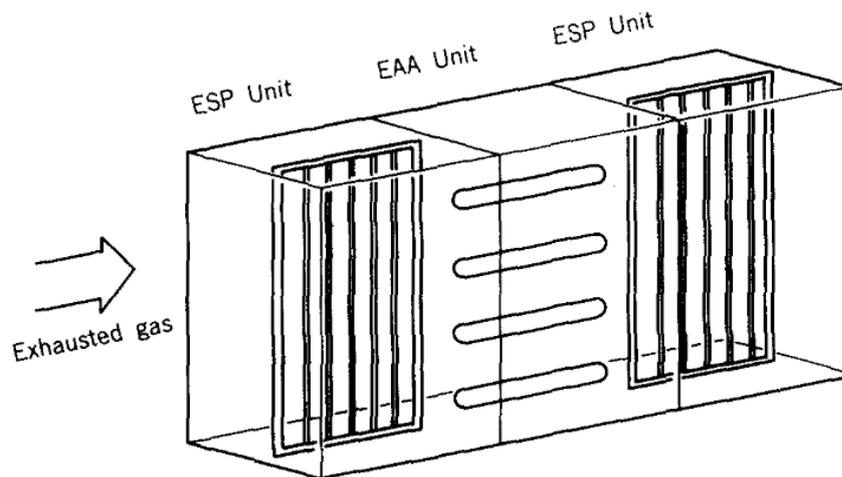


Figure 1.7 The basic structure of a new-type ESP) designed by T. Watanabe *et al.*

(T. Watanabe *et al.* 1995).

A. Laitinen *et al.* (1996) took an experimental study for a method of increasing efficiency of ESPs for collecting of fly ash particles of submicron size. An alternating electric field was used to induce agglomeration of bipolar charged particles (bipolar AC-agglomeration). An AC-agglomerator with bipolar corona charger was constructed. Vegetable oil was used for test aerosol with total mass loading was 0.2 gm^{-3} ($5 \times 10^6 \text{ particles cm}^{-3}$), mass median diameter was $0.5 \text{ }\mu\text{m}$, count median diameter was $0.2 \text{ }\mu\text{m}$, and geometrical standard deviation was 1.8. In agglomerator that residence time was 4.8 s and electric field was 5.0 kV cm^{-1} (rms). The agglomeration efficiency was investigated by the system as shown in Figure 1.8. The decreasing of number concentration of $0.1\text{-}1.0 \text{ }\mu\text{m}$ sized particles was found to be between 17 and 19%

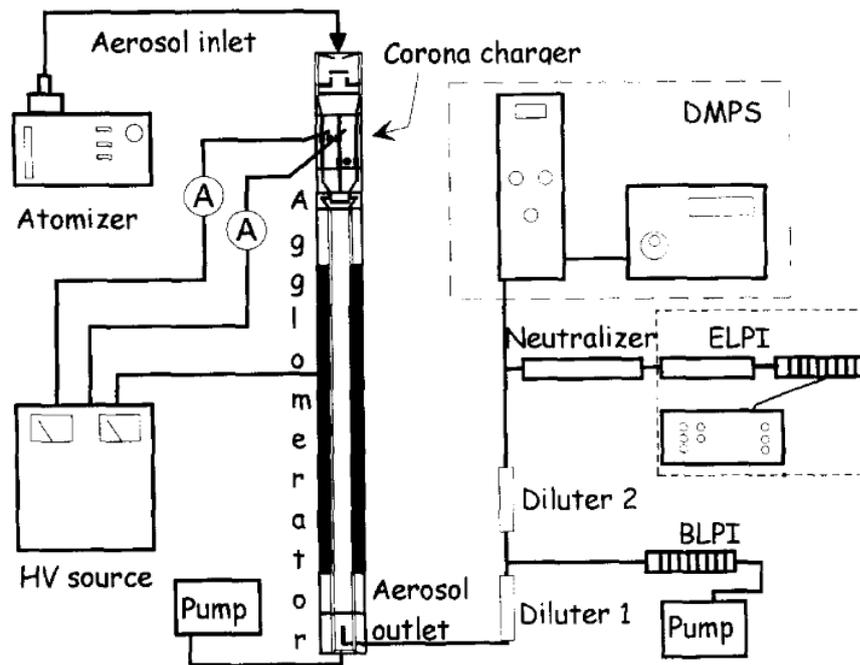


Figure 1.8 Agglomerator test system. An aerosol generator, high voltage source and pump are shown to the left. The measurement system, shown on the right, consists of a Differential Mobility Particle Sizer (DMPS), electrical low-pressure impactor (ELPI) and Berner-type low-pressure impactor (BLPI)

(A. Laitinen *et al.* 1996).

Y. Koizumi *et al.* (2000) analytically investigated the agglomeration coefficient of bipolar-charged aerosol particles. The electrostatic agglomeration coefficient of bipolar charged particles was calculated using a two particles collision model to evaluate the effect of external electric field on the particles agglomeration. The model was based on kinetic equations which traced the trajectories of two particles under an external electric field, Coulomb's force, and image force, and air viscosity. The calculated coefficients showed that the AC electric field with low frequency was very effective for bipolar-charged particles agglomeration. In particular, water droplet gave a large agglomeration coefficient due to its large dielectric constant.

J.H. Ji *et al.* (2004) investigated experimentally the agglomeration characteristics of bipolar charged particles under an AC electric field and charging characteristics of particles by wire-to-plate type DC corona chargers. As shown in Figure 1.9, a laboratory-scale setup was built and experiments were conducted. They discussed the effects of DC and AC fields on the size distribution variation of particle. By the two corona chargers which applied voltages of +8 and -8kV DC, respectively. The agglomeration section was applied by AC electric field 3.9 kV/cm, and the residence time was adjusted to 1 s. A cascade impactor (MOUDI) used to measure a Particle size distribution. The reduction of submicron particles was 25-29% when AC fields with 60-500 Hz were used. The number of charges per particle was measured when the polarities of two corona chargers were either positive or negative. Current-voltage characteristics of the corona chargers were procured for high-mass loading condition and compared with those for the no mass loading. 70-90 % of corona-induced ions attached to Dioctyl Phthalate (DOP) particles in the negative corona charger. The results showed that the higher mass loading caused lower particle charges.

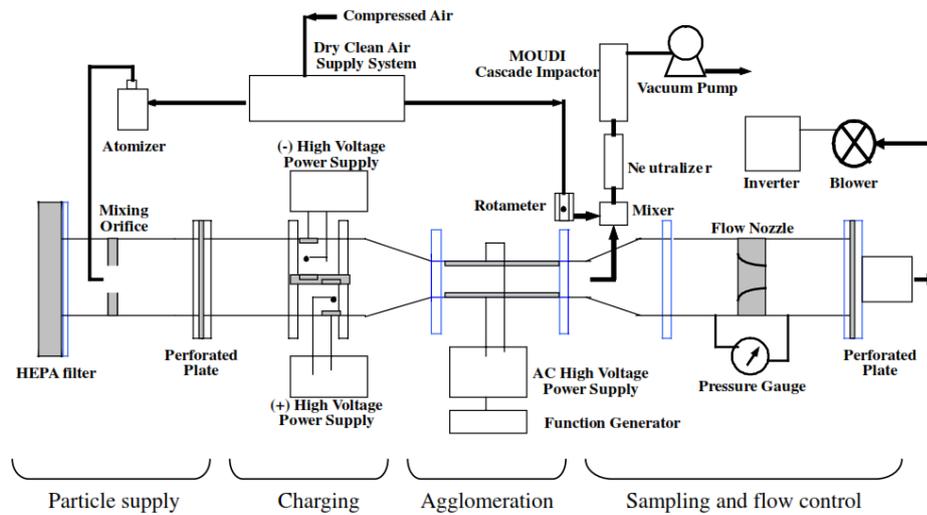


Figure 1.9 The Schematic of experimental setup for agglomeration characteristics

(J. H. Ji *et al.* 2004).

B. Tan *et al.* (2007) investigate experimentally the effect of an external DC electric field on the efficiency of bipolar charged particle agglomeration. A DC-electric field was exerted in an ESP to induce the agglomeration of bipolar charged particles. Water with an atomizer was used for generated the test particles with their average diameter was 7.71 μm . The size distribution and the particle number concentrations were measured by a phase Doppler anemometer (PDA). Systematic experiments were conducted to investigate the agglomeration efficiency of the system as show in Figure 1.10. The percentage decreased in number of submicron particles was found to be about 10.7%.

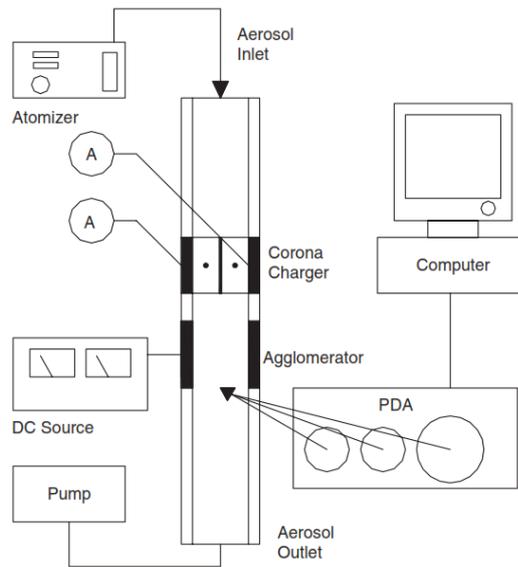


Figure 1.10 Agglomerator test system. The aerosol generator, the high voltage source and the pump were on the left. The measurement system was on the right (B. Tan *et al.* 2007).

S. Kanazawa *et al.* (2009) experimentally studied the fundamental characteristics of agglomeration and precipitation of submicron particles in a two-stage ESP with a bipolar charging. Figure 1.11 shows the ESP consists of two sections are bipolar charging and an electric field. Trajectories of smoke particle were observed and size distributions were measured with parameters as the charging voltage and the electric field strength. Moreover, a corona field calculation method used to calculate particle and theoretical particle trajectories were compared with experimental results. As a typical result, 0.3–1 μm particles decreased to only 18% (75% without bipolar charging), while 1–5 μm particles increased to about 82% (25% without bipolar charging). Under an optimum condition, the collection efficiency for submicron particles was about 80%.

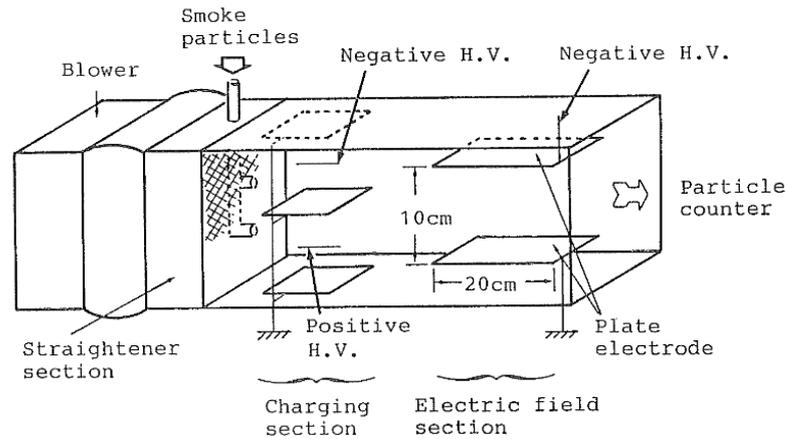


Figure 1.11 The experimental apparatus of two-stage ESP with a bipolar charging

(S. Kanazawa *et al.* 2009).

J. Zhu *et al.* (2010) designed and experimentally studied an ESP with a bipolar pre-charger for charge-induced agglomeration and fine particle collection. The wire-plate type ESP had five fields with its length, height and width of 1000 mm, 1000 mm and 300 mm, respectively. The total ESP area was 1.38 m². The saw-like discharge electrode had a tip-distance of 22 mm. The gap between the corona electrodes was 44 mm. The gas flow rate could be adjusted up to 1000 m³/h, which corresponded to gas velocities of 0.78 m/s inside the ESP and 11.4 m/s inside the pre-charger, respectively. The bipolar pre-charger was placed in front of the ESP with its length, height and width of 1000 mm, 150 mm and 150 mm, respectively. The pre-charger consisted of one positive and one negative charger as shown in Figure 1.12. The number collection efficiency of ESP dropped to 90% for particle with diameters of about 0.2 μm and 3 μm. For other particles, the value was around 94%-95% and the grade collection efficiency could be significantly increased to about 95%-98% for all particle sizes due to the charge-induced particle agglomeration with the bipolar pre-charger.

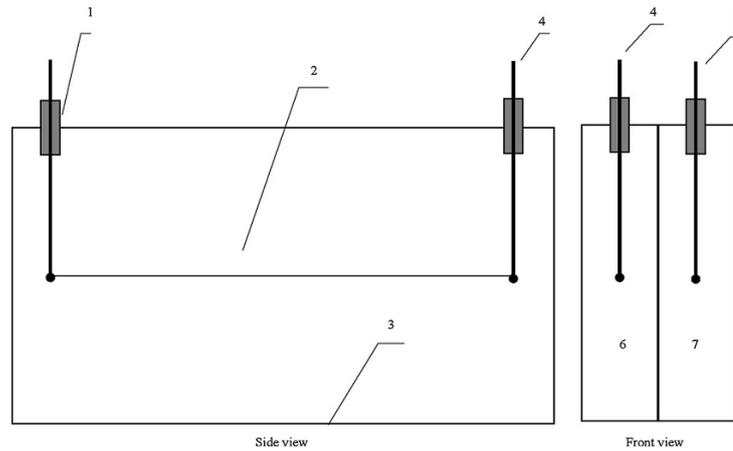


Figure 1.12 Side and front views of the pre-charger 1: insulator; 2: corona wire; 3: duct; 4: positive high-voltage connector; 5: negative high-voltage connector; 6: positive corona charger; 7: negative corona charger. The length of two identical wires was 1000 mm. The height and width of each corona charger were 150 mm, respectively

(J. Zhu *et al.* 2010).

1.2.3 NTP technique for Submicron Particle removal

Now a day, several techniques have been used to air pollutants controlled. When electric field is applied to a gas, the ionization process occurs due to electric energy discharge via the impact of gas molecules or atoms with high energy electrons, which results in the formation of plasma, the fourth state of matter in which electrons and ions coexist in the gas. If the thermal energy of electrons is higher than thermal energy of ions, the plasma is called NTP, or cold plasma discharge which is strongly related with the plasma produced reactive species and photon. Due to the electron energy is higher the energy of ions and the neutrals, thus reducing the energy requirements to remove the pollutants. The NTP technique has been also investigated widely for cleanings of harmful gases, and for other applications such as methane conversion.

A. Mizuno *et al.* (1986) investigated experimentally a method for the sulfur dioxide removal from exhaust gas using pulsed streamer corona. They evaluated performance of a new method using pulsed streamer corona for the removal of SO₂ from humid air. The pulsed streamer corona produced radicals that enhanced the gas-phase chemical reaction that converted SO₂ to acid mist and/or particle matter. The particles were then collected by conventional ESP. The SO₂ removal efficiency was compared with the electron-beam and dc corona flue-gas treatment processes. The comparison demonstrated the advantage of the novel method.

J. S. Clements *et al.* (1989) developed a pulse-energized electron reactor which utilizes pulsed streamer corona for the combined removal of SO₂, NO_x, and particles from effluent gases as shown in Figure 1.13. In the pulse-energized electron reactor process, fast-rising narrow high-voltage pulses were superimposed on a DC-bias voltage and applied to non-uniform electric field geometry to generate pulsed streamer corona. The pulsed streamer corona produced energetic free electrons, which dissociated gas molecules, forming radicals. These radicals caused chemical reactions that converted SO₂ and NO_x into acid mists and/or solids, which could be removed from the gas stream by conventional means. The pulsed streamer corona also produced ions, and between pulses the ions charge the fly-ash particles, which are then collected by the DC-bias field. The pulse-energized electron reactor performance was tested in a humid air stream with an initial SO₂ concentration of 1000 ppm, more than 90 percent of the SO₂ was removed with a small power requirement. A treatment was demonstrated by introducing high-resistivity fly-ash into the gas stream. The fly-ash collection efficiency of the pulse-energized electron reactor was significantly better than that of a conventional DC wire-cylinder ESP when the electrodes of both were covered with a high-resistivity layer. Most of the fly-ash that escaped collection by the reactor was agglomerated, and subsequently collected by an ESP or fabric filter. Furthermore, the SO₂ removal efficiency was improved. In addition, some of the SO₂ conversion products may lower the resistivity of the fly-ash, thereby facilitating collection in an ESP by reducing back corona. The practical electrode configurations (wire-to-cylinder or wire-to-plate) were conducted and the performance results of the reactor were found to be improved.

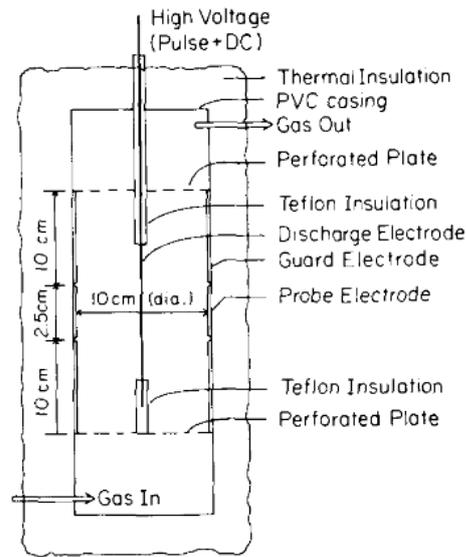


Figure 1.13 A pulse-energized electron reactor developed by J. S. Clements *et al.*

(J. S. Clements *et al.* 1989).

M. Okubo *et al.* (2001) experimentally investigated the decomposition of acetaldehyde (CH_3CHO) in tobacco smoke odor using an ESP and a NTP reactor as shown in Figure 1.14. They obtained more than 90% of decomposition efficiency with the use of the NTP under dry air. However, under humidified the decomposition efficiency was deteriorated. Higher collection efficiency was achieved for a particle size of $0.6 \mu\text{m}$ than that of $0.3 \mu\text{m}$ although the overall over collection efficiency exceeded over 99%. When, ESP and NTP technologies were combined with together leaded to the breakthrough of the conventional indoor electric air cleaner technology.

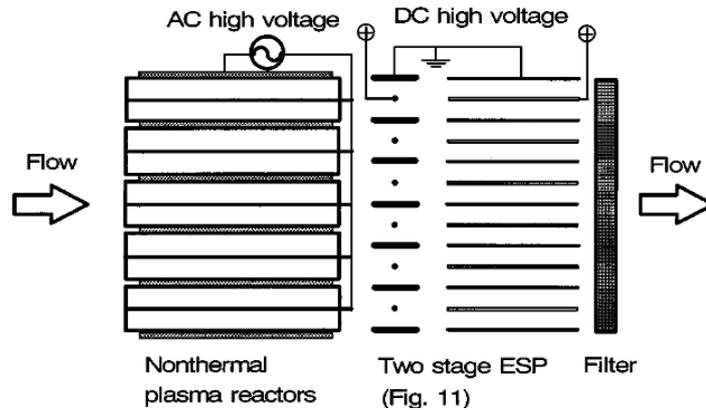


Figure 1.14 Schematic of new electric air cleaner system developed by
M. Okubo *et al.*

(M. Okubo *et al.* 2001).

J. H. Byeon *et al.* (2006) experimentally investigated the collection characteristics of submicron aerosol particles by using a lab-scale, two-stage, and barrier discharge type ESP as shown in Figure 1.15. They measured the size distributions of bimodal submicron aerosol particles and estimated the collection efficiency of the particles for a hybrid two stage ESP comprised of a dielectric barrier discharge (DBD) charger as a particle charger and an ESP as a charged particle collector. Nano-sized particles of NaCl (30–100 nm) and dioctyl sebacate (DOS) (50–800 nm) were generated by evaporation–condensation and atomization, respectively. Various electrical and flow conditions were applied on the DBD charger: AC applied voltage of 9–11 kV, frequency of 60–120 Hz, and air flow rate of 60–180 L min⁻¹. The particle collection efficiency increased as the AC applied voltage increased at a fixed frequency–flow rate, whereas the efficiency decreased as the frequency and the flow rate increased at a fixed AC power–flow rate and a fixed AC applied voltage–frequency

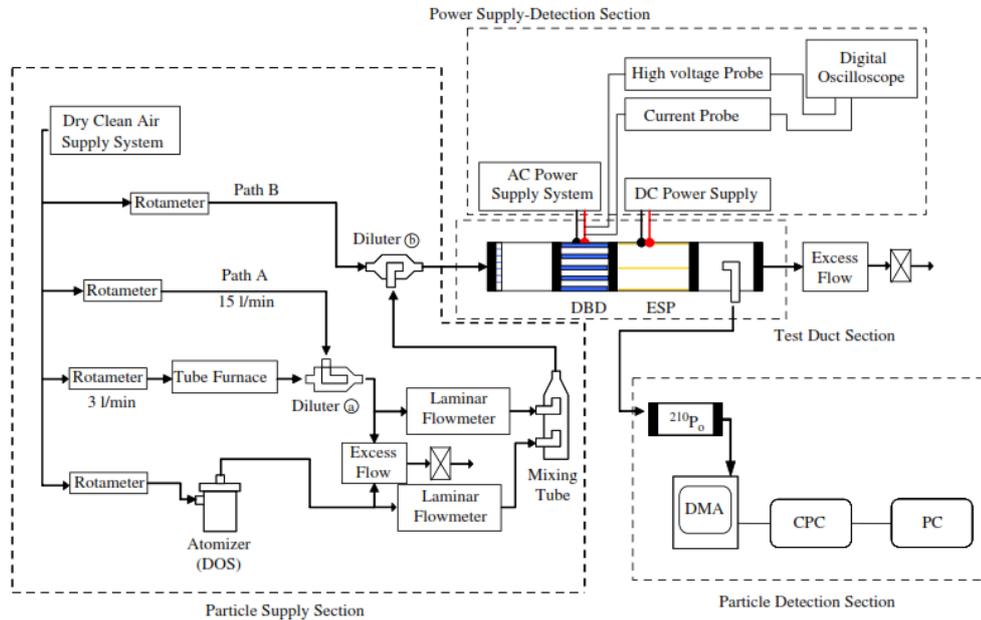


Figure 1.15 Schematic of experimental setup for collection of submicron particles by an ESP using a dielectric barrier discharge (J. H. Byeon *et al.* 2006).

B. Dramane *et al.* (2009) investigated experimentally efficiency of a Dielectric Barrier Discharges (DBDs) for the collection of submicron particles. The experiments were performed with particles having a mean size of about $0.3 \mu\text{m}$ incense from incense. An aerosol spectrometer was employed for characterizing the size distribution of these particles at the outlet of Wire-to-Cylinder and Plate-to-Plate DBD reactors employed an aerosol spectrometer. The collection efficiency was estimated for various applied voltages (6 – 26 kV, 1 – 2000 Hz), and airflow rates of 1.6 – 24 L/min. The discharge mode was diffuse, in the case of the axisymmetric configuration, and filamentary, in the case of the planar configuration. When flow rate increased, the discharge current and the electric power decreased in both cases. This effect was less pronounced with the planar configuration. Results obtained with the aerosol spectrometer showed that the particle collection efficiency of both reactors was higher at high applied voltage and low flow rate; it decreased at high frequency because of particle oscillations, and at low frequency due to the intermittent nature of

the discharge. The frequency range for which the collection efficiency was higher than 90% is wider in the case of Wire-to-Cylinder reactor.

1.3 Aims of the Study

- To experimentally evaluate performance of the charging and agglomeration of submicron particles by using the pulse corona plasma excited ESP under controlled operating condition of applied voltage magnitude, particle concentration, gas flow rate.
- To developed the empirical model for the filtration of submicron particles by using the pulse corona plasma excited ESP.
- To design, construct, and test the prototype of the pulse corona plasma excited ESP

1.4 Benefits of the Study

- Clear explanation of the factors which affect the submicron charging and agglomeration in the pulse corona plasma exited ESP.
- The prototype of electrostatic precipitation system using pulse corona plasma technique can be obtained.

1.5 Scope of the Study

- NTP technique, pulse corona plasma is used in this study.
- Study of the experimental factors were as follows;
 - Applied peak voltage <math><50 \text{ kV}_p</math>
 - Pulse duration >1 μs
 - Mean current <math><2 \text{ mA}</math>
 - Gas flow rate in the range of 1.0 to 8.0 l/min
 - Gas temperature in the range of 25 to 300 $^{\circ}\text{C}$.
- The particle size in the range of 0.3 to 5.0 μm is considered.
- In this study, spherical particles with uniform distribution are assumed.