“I hereby declare that I have read through this report entitle “Electrostatic Chamber Development for Dust Collector” and found that it has been comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”.

Signature	: …………………………………
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ELECTROSTATIC CHAMBER DEVELOPMENT FOR DUST COLLECTOR

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This report is submitted in partial fulfillment of the requirements for the degree of the Bachelor of Electrical of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

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“I declare this report entitle “Electrostatic Chamber Development for Dust Collector” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree”.

Signature : ………………………………….

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ABSTRACT

Electrostatic dust collector is a chamber that function to trap dust or particle. The operation is based on electrostatic precipitator(ESP) which is widely used in industry as an important equipment for environmental protection. Electrostatic dust collector is designed to be used as indoor air filter. In this project, principles of electrostatic precipitation such as particle charging, electric field strength and collection efficiency are reviewed. Particulate matter with dimension less than 2.5µm (PM 2.5) can penetrate deep into the human respiratory system. Air filter can help to remove airborne bacteria from operating room air to help prevent postoperative infection. ESP can also remove dusts and gaseous pollutants. These new advancements will widen the field of application of electrostatic precipitator. In this project, the electrostatic dust collector was developed in an acrylic box with a copper wire as a discharge electrode, placed between two plate collecting electrodes which is aluminium plate. The negative DC voltage was applied to the wire electrode. The factor that affected collection efficiency such as size of particle, type of dust and supply voltage will be discussed in this report.

ABSTRAK

Penangkap habuk elektrostatik adalah sejenis bekas yang berfungsi untuk memerangkap habuk atau zarah. Fungsinya adalah berdasarkan *Electrostatic Precipitator(ESP)* yang mana digunakan secara meluas dalam industry sebagai alat yang penting untuk melindungi alam sekitar. Penangkap habuk elektrostatik direkauntuk digunakan sebagai penapis udara untuk kawasan tertutup. Dalam projek ini, prinsip ESP seperti mengecas zarah, kekuatan medan elektrik dan kecekapan memerangkap dikajisemula. Bahan zarah dengan dimensi kurang dari 2.5µm (PM 2.5) mampu menembusi ke dalam system pernafasan manusia. Penapis udara dapat membantu untuk menghapuskan bakteria yang dibawa oleh udara dari bilik pembedahan untuk mengelakkan jangkitan kuman. ESP juga boleh mengasingkan habuk dan gas yang tercemar. Penambahbaikan ini akan meluaskan penggunaan ESP. Dalam projek ini, penagkap habuk elektrostatik dibina dalam kotak akrilik dengan menggunakan wayar sebagai elektrod penyah-cas, diletakkan di antara dua plat pengumpul yang merupakan plat alumina. Voltan DC negative disambungkan kepada elektrod wayar. Faktor yang mempengaruhi kecekapan mengumpul seperti saiz zarah, jenis habuk dan voltan yang dibekalkan akan dibincangkan dalam laporan ini.

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INTRODUCTION

1.1 Motivation

In order to prevent air pollution due to industrial activity, engineers had developed a device to control air pollution known as electrostatic precipitator. This device very helpful to increase air quality and fulfil the requirement for air quality index. In an electrostatic precipitator, a static charge attracts contamination particles to electrified plates of metal, similar to how static electricity in clothing attracts bits of lint. This method works very well for power plant area, cement factory and dusty area.

Furthermore, quality of air nowadays also affected by the pollution of vehicles and haze. Thus, indoor air quality also polluted. Polluted air is harmful to health such as lung problem. In order to keep the indoor air quality clean, the development of chamber for dust particles based on electrostatic concept which has same principle as electrostatic precipitator is done in this project.

1.2 Project Background

Electrostatic dust collector is a chamber that use the electric field concept to trap the dust and particle to produce clean air. The concept of electrostatic dust collector is similar as Electrostatic Precipitator which is widely used in industry. By using this device, the pollution of air can be controlled. Figure 1.1 shows one of the type of electrostatic precipitator used in industry especially at the coal-fired power plant and factory such as cement manufacturer factory.

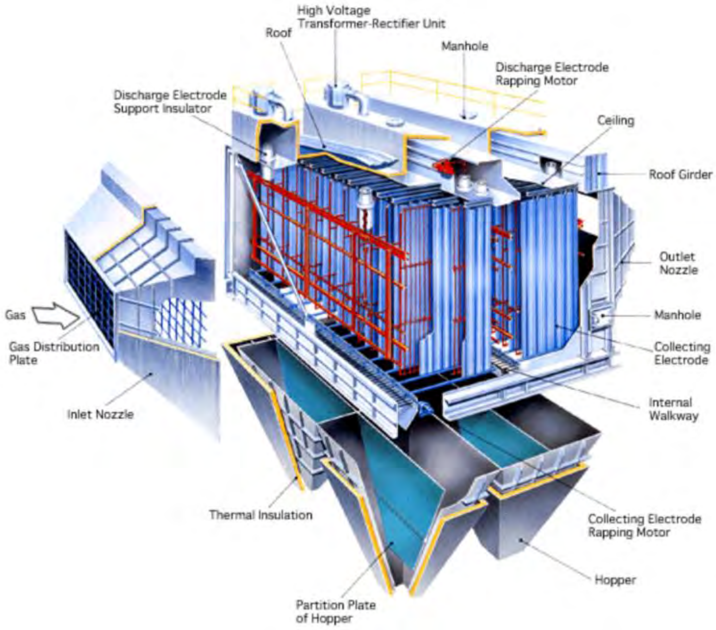

Figure 1.1: Electrostatic Precipitator

Basic principle of this device is, when dc high voltage is supply to the electrode, corona effect will ionize the surrounding atmosphere. Particles that enter the chamber will collide with the free electrons and form charged particles (ions). This charged particles move toward the collecting plate due to electrostatic force.

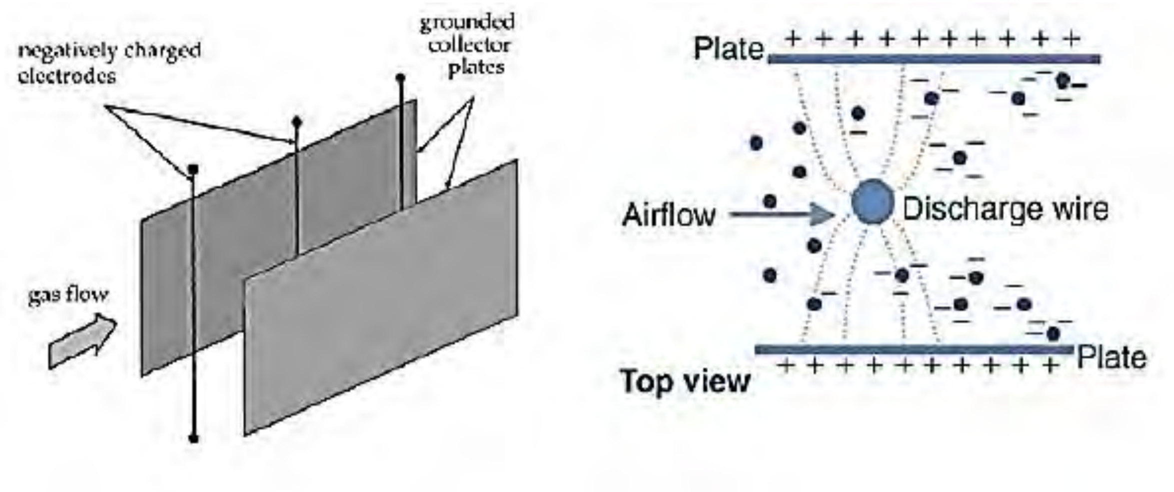

Figure 1.2: Basic Concept of Electrostatic Dust Collector

Clean air can be defined as dry air that are free from air pollution. Generally, the lower the concentration of airborne pollutants, the better the air quality. Sometimes, there are toxic metal found in air especially for the area which is near to the coal-fired power plants. Example of toxic metals are Arsenic(As), Nickel(Ni), Mercury(Hg), Strontium(Sr), Selenium(Se) and Beryllium(Be)[1].

It is important to have a good air quality especially in office or home where the human being spend time mostly. Polluted air can cause a lot of disease to people such as lung cancer, asthma and lung dysfunctions. Thus, the indoor air quality need to be concern. Electrostatic dust collector can help us to improve indoor air quality.

1.3 Problem Statement

Clean air is important for human being to ensure the healthy life. Dust will make the quality of air decreases. Small particle in air cannot be seen with our eyes due the size which is very small and light. Building and road construction near to our living area cause a lot of dust. Residential area which are located near to the industrial area also face the air pollution problem. Therefore, a lot of research have been done to produce a product which can collect dust and small particle in air. One of the solution is by using electrostatic concept. Electrostatic dust collector can trap particle which is smaller than 5 μm compare to the other air filter. Thus, the research about this concept will be conducted and the best design will be suggested as a product for control indoor air quality.

1.4 Objectives

The objectives of this project are:

i. To design and develop dust or particle collector chamber based on electrostatic concept
ii. to analyse the effect of size and type of dust to the efficiency of electrostatic dust collector
iii. To investigate the effect of size of cables to the efficiency of electrostatic dust collector
iv. To compare the effect of different supply voltage to the efficiency of electrostatic dust collector.

1.5 Scope

The focus of this project is to increase the indoor air quality. The scope of this project is to design electrostatic chamber to collect dust or ultrafine particle. This project consists of discharge electrode and collecting plate. The space between the electrode and collecting plate are important to study to prevent breakdown. Spacing 5 cm is tested in this project. Different size of cables is tested to see the effect to the collection efficiency. Size of cable used are 1.0, 2.5, 4.0, 6.0 and 10 mm^2. Two type of dust, sawdust and ash with different size will be tested is in range 1.0 µm to 5.0 µm (fine and finest). This project need high voltage supply (0-30 kV) in order to ionize the particle or dust.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Rigorous new regulations in dust emission by power plants and industrial processes have brought new requests for dust control devices. These new regulations will require most extreme molecule outflows on the level of 10–50 mg/Nm^3 and confinements to the discharge of fine particles smaller than 2.5 mm. To meet these necessities, new techniques for gas cleaning with collection efficiency higher than 99% have been designed and tested [2]. Table 2.1 show the air quality guideline by the World Health Organization (WHO) [3].

Table 2.1: Guideline by WHO

Type of Ash	Guideline
Particulate Matter smaller than 2.5 μm ($PM_{2.5}$)	10 μg/m^3 annual mean 25 μg/m^3 24-hour mean
Particulate Matter between 2.5 μm and 10 μm (PM_{10})	20 μg/m^3 annual mean 50 μg/m^3 24-hour mean
Ozone (O_3)	100 μg/m^3 8-hour mean
Nitrogen Dioxide (NO_2)	40 μg/m^3 annual mean 200 μg/m^3 1-hour mean
Sulphur Dioxide (SO_2)	20 μg/m^3 24-hour mean 500 μg/m^3 10-minute mean

A conventional electrostatic precipitator generally comprises of a series of high voltage and relating collector plates. There are many shapes of electrodes used in electrostatic precipitators such as plate, wire, flat plate and tubular. The high voltage electrodes are ordinarily wires. Particles are charged and subsequently isolated from the gas stream affected by the electric field created between the terminals. In a single-stage electrostatic precipitator, the electric field, used to produce the corona discharge is mainly used to attract and subsequently expel the charged particles [4]. In a two-stage precipitator, charging and expulsion of particles occurs in independent electric fields [2][4].

ESP is utilized to remove contaminations from large gas flow (hundreds of thousands m^3/h). The efficiency of ESP's relies upon voltages waveform and amplitude, type of power supply, current control, geometry of electrostatic precipitators, type of discharge wires, gas composition, particles distribution, gas flow, temperature, gas pressure and particles velocities distribution [5].

The basic operation of the ESP is that the gas particle will passes through an electric field and will be ionized. Then, the charged particle will diverted over the electric field to relocate and be deposited on the collecting plate [6].

2.2 Ionization Process

Ionization is one of the important process in Electrostatic Precipitator. The particle that enter ESP will be charged and produced ion. Generally, the particle that enter ESP will pass through strong electric field and accelerated rapidly and attains a high velocity. When this particle collides with stray electron from any variety of sources, it has enough energy to knock one or more electron loose from its shell, so the particle (gas molecule) will ionize [7].

Ionization is a process of freeing an electron from a gas atom with the simultaneous production of a positive ion. Mechanism of ionization can be categorised to ionization by collision, photo-ionization, secondary ionization process. Gas becomes a conductor when a high-voltage is applied between the two electrodes immersed in a gaseous medium and an electrical breakdown occurs [8].

2.2.1 Ionization by Collision

During the ionization by collision, number of new electron and positive ion increasing when a free electron collides with a neutral gas atom.

Based on Figure 2.1, when electric field E is applied across two plane parallel electrodes (consider a low-pressure gas column), any electron starting at the cathode will be accelerated more and more between collisions with different gas particles during its travel towards the anode [8]. The ionization will take place when the energy (ε) gained during this travel between collisions greater than the ionization potential, V_i. That is the energy required to release an electron from its atomic shell. The expression below explained this process:

$$e^- + A \xrightarrow{\varepsilon > Vi} e^- + A^+ + e^- \tag{2.1}$$

where, A is the Atom, A^+ is the positive ion and e^- is the electron.

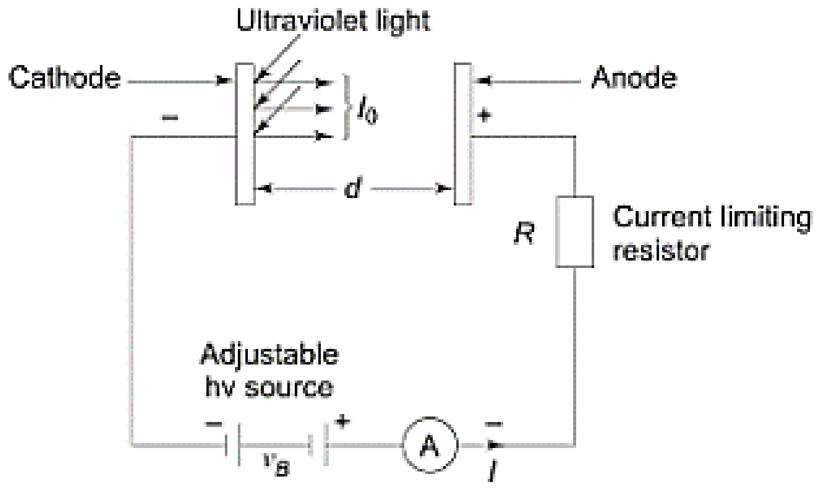

Figure 2.1: Arrangement for study of a Townsend discharge

A few of electrons produced at the cathode by some external means ionize neutral gas particles and producing positive ions and more free electrons. The electron then makes ionizing collision themselves thus increasing the number of electrons. Then, the process will repeat itself.

2.2.2 Photo-ionization

Photo-ionization happen when the amount of radiation energy consumed by an atom surpasses the ionization potential [8]. Process which radiation can be consumed by atom or molecule are:

a) excitation of the molecule to a higher energy state
b) continuous absorption by direct excitation of the particle or separation of diatomic molecule or direct ionization.

Similarly, as an energized molecule discharges radiation when the electron returns to the lower state or to the ground state, the reverse process occurs when an atom absorbs radiation. The reversible process can be represented as:

$$hv + A \leftrightarrow A^{*} \tag{2.2}$$

Ionization occurs when

$$\lambda \le c \cdot \frac{h}{V_i} \tag{2.3}$$

where;

h = Planck's constant

c = velocity of light

$\lambda =$ the wavelength of the incident radiation

V_i = ionization energy of molecule

Based on the equation, the greater ionization energy, the shorter the wavelength of the radiation capable of causing ionization. It was shown experimentally that a radiation having a wavelength of 1250A is equipped for creating photo-ionization of practically gasses.

2.2.3 Secondary Ionization Process

Secondary ionization process is the process of producing secondary ionization which sustain a discharge due ionization by collision and photo-ionization. It can be classified into three section.

a) Electron Emission due to Positive Ion Impact

Positive ion is formed due to ionization by collision or photo-ionization. Emission of electron from the cathode causes by approaching of the positive ion to a metallic cathode by giving up its kinetic energy on impact. If the total of kinetic energy plus with ionization energy is greater than twice the work function of metal, an electron will be ejected and the ion will be neutralised by the second electron. This probability depends on the material of electrode and kind of gas used.

b) Electron Emission due to Photons

In order to release an electron from metal (its atomic structure), enough energy is needed. Photon of ultraviolet light also can supply the energy. Electron emission happen at the critical condition:

$$h \cdot v \geq \varphi \quad (2.4)$$

where

φ = the work function of the metallic electrode

The relationship of the frequency (v) known as threshold frequency is expressed by:

$$v = \frac{\varphi}{h} \quad (2.5)$$

If the incident radiation has a greater frequency than the threshold frequency, then the excess energy goes partly as the kinetic energy of the emitted electron and partly to heat the surface of electrode.

c) Electron Emission due to Metastable and Neutral Atoms

Metastable atom is the particle have longer lifetime (10^{-3} s) than ordinary particle (10^{-8} s). Impact of excited (metastable) atoms will eject electron from the metal surface by provided energy that sufficient to overcome work function. The most easily method to observe this process is with metastable atom due to its lifetime. In the ground state, neutral atoms give rise to secondary electron emission if their kinetic energy is high (≈ 1000 eV).

2.2.4 Electron Attachment Process

Electron attachment process is the process that form negative ion by the collision which electron will attached to atom. The energy of the electron and the nature of the gas is the important factor for this process. All the insulation gases such as O_2, CO_2, Cl_2, F_2, C_2F_6, C_3F_8, C_4F_{10}, CCl_2F_2 and SF_6 have this property. Electron attachment process can be presented as:

$$Atom + e^- + k \rightarrow negative\ \text{atomicion} + (E_a + \text{K}) \quad (2.6)$$

E_a = Electron affinity

K = Kinetic energy

Insulation gases have the vacancies in their outermost shells so they have an affinity for electron. The attachment process plays a very important role in the removal free electron from an ionized gas when arc interruption occurs in gas-insulated switchgear.

2.3 Corona Discharge

Corona discharge is a discharge in the gas to appear at points with highest electric field intensity, namely at sharp points or where the electrodes are curved or on transmission lines when there is increase in voltage in non-uniform electric field. This type of discharge will ensure production of electron in ESPs so that ionization process occur.

In ESPs, generation of corona occur between the parallel electrode, which is connected to a dc high-voltage supply, and the grounded outer electrode [9]. Ions produced in the discharge will charging the particle are subsequently accelerated by the electric field forces toward the outer electrode. The process of electrostatic precipitation relies on upon this movement of the charged particles toward the collector electrode.

Non- uniform electrical field is required to produce corona discharge generation in the air at atmospheric conditions, which can be achieved by using a small diameter wire electrode, energized from a high-voltage supply, and a metallic plate or cylinder, connected to the ground, which is designated as collecting electrode. In order to improve the air quality and to reduce the emissions of smoke, fumes, and dust, industrial ESPs are used [6].

The voltage-current characteristics of a corona discharge [10] normally presented as

$$I = AV\ (V - V_c) \qquad (2.7)$$

Where:

A is a constant,

V = the corona starting voltage

I = the electric current

V = the applied voltage

The flashover voltage of negative corona at an electrode separation, d greater than 5 cm, is ~15d kV, and that of the positive corona is about half that of the negative corona. Generally, the negative polarity is utilized due to the higher flashover voltages of negative corona, giving a larger margin of operating voltages. For indoor air cleaning, the positive polarity is utilized because of lower ozone generation.

Ahmed Kasdi[11] had been conducted an experiment about "Computation and measurement of corona current density and V-I characteristics in wires-to-plates electrostatic precipitator". The researcher used different configuration of electrode in order to test electrostatic precipitator performance. From this experiment, few results were obtained. For the same applied voltage, as the quantity of wire used increases the collected current increases too. This is due to increasing of discharge electrode. For the same voltage, the corona discharged current increases significantly with the augmentation of the wire-to-wire spacing. This is due to the shielding effect exerted by each wire on the other.

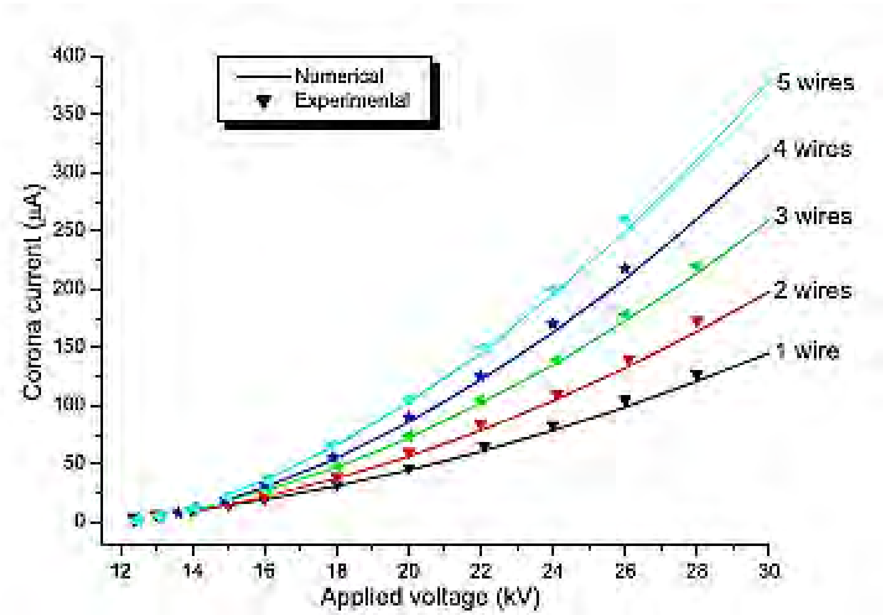

Figure 2.2: Current-Voltage characteristics for different number of wires

2.4 Operational Properties of ESP

Electrical energy is required for particle charging, gas ionization, particle coagulation or vapour condensation [2]. The overall collection efficiency of any cleaning device can be determined from the formula:

$$\eta = \frac{m_{out}}{m_{in}} \tag{2.8}$$

Where m_{out} and m_{in} are the concentration of the particle mass at the outlet and the inlet of the device. ESP is a device which use electrostatic concept to collect dust. It has various shape of electrode, sharp electrode or thin wire stretched along the axis of a cylinder.

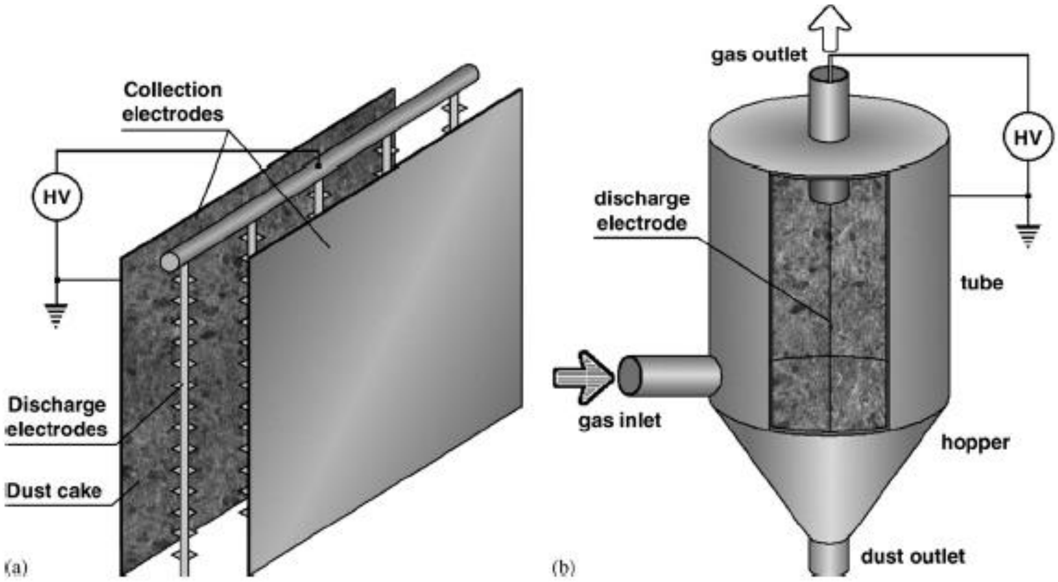

Figure 2.3: Two types of ESP (a)Parallel plate (b) Tubular

The charging particles mechanism which are most important consist of:

a) **Field charging**. Ions are headed to the molecule because of electrostatic force caused by an external electric field. This force is adjusted by the repulsive force of the charge granted to the particle.

b) **Diffusion charging**. This is because of the kinetic energy of gaseous ions that bombard the molecule independently of the electric field.

Field charging is the dominant mechanism for particle larger than 1μm while the ion diffusion is dominant for particle smaller than 0.1μm.

The current density on the collection electrode is usually in range of 0.1-1mA/m^2 and the energy consumption is usually the order of 0.3-108MW/1000 N m^3 [2].The collection efficiency of an ESP can be estimated from the Deustch formula:

$$\eta = 1 - e^{-V_m{}^{A/V}} \qquad (2.9)$$

v_m = the mean migration velocity of the particle across the precipitator

A = the cross-sectional area of the precipitator channel

V = the gas flow rate

From this formula, the migration velocity or cross-sectional area will increase by increasing the distance between the plates or decreasing the gas flow rate.

2.5 Gap between Plate of ESP

Theoretically, the smaller spacing between the parallel plate, the higher the current density at the same operational voltage. There is no exact relationship between the current density at collecting plate and efficiency of ESP was found [12]. The wider space between plate is used to increase overall collection efficiency. The optimum electrode spacing is between 400 to 600mm. on the other hand, there was no strong evidence for that assumption [2]. The upper limit of this distance is difficult to predict. Table 2.2 explained about the plate spacing can be divided.

Table 2.2: Comparison of Plate Spacing

Reference	Gap Distance/mm	Comment
Anatol Jaworek[2]	300	This distance is better for collecting dust of low resistivity
	400	Optimal for the collection of high resistivity dust
	450	Suitable for particle larger than 1μm. This spacing will be obtained maximum collection efficiency and optimal energy consumption. But for smaller particles, no significant effect was noticed.

A large distance between electrodes allows the applied voltage to be higher and electric fields at the collection electrode can also be higher due to decrease space charge effects.