

Experimental Investigation of Removal of Flue Gas Emissions Exhaust from Municipal Solid Waste Incinerator using Photo-Voltaic based Electrostatic Precipitator

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Abstract

For the past decades, the flue gas emitted from Municipal Solid Waste Incinerator, Power Plant, and various industries are a permanent problem for the environment and has been affecting human life. Many flue gas filtration devices have been emerging out over the years. Although the Electrostatic Precipitator was an appropriate device due to high filtration efficiency, little pressure drop and energy efficiency, the cost and design of the Electrostatic Precipitator is a major restriction for manufacturers and end-users. With recent advances in technology, designing a cost-effective and less complex electrostatic precipitator has become mandatory. This article aims to design and develop a solar-powered cost-effective Needle-Plate type electrostatic precipitator which includes a static power converters and high voltage Transformer-Rectifier (T-R) set with an input voltage as 230V AC, output voltage as 80kV Direct Current (DC) and output current of 40mA for mitigation of Flue gas emissions exhaust from Municipal Solid Waste Incinerator. The analysis of flue gas at ESP inlet and outlet has been performed using Ecotech stack sampler and flue gas analyzer. The obtained experimental results are validated with Emission standards provided in the Solid Waste Management rules book-India 2016.

1. Introduction

Municipal Solid Waste (MSW) Management, a decisive factor in the direction of sustainable urban growth, includes characterization, storage, treatment, segregation, collection, and disposal of solid waste to reduce its harmful impact on the atmosphere (Kumar et al., 2009). The quantity of MSW enlarges in corresponding to economic growth, owing to extreme consumption (USEPA, 2002). Solid Waste is categorized into three types, namely degradable, partially degradable, and non-degradable materials and it is generally collected from streets (Arvind et al., 2008). Recently all developing countries are paying more attention to MSW management because most people do not have enough facilities to utilize MSW storage service (Schubeler, 1996). As a result, proper management of MSW is significant for human health and the environment. In several countries, MSW is treated in three ways, such as incineration, landfilling, and recycling (USEPA, 2012). The incineration method of treatment is cost-effective and ash produced from this treatment method can produce expensive materials (Huang et al., 2006). The Primary advantage of incineration is the reduction of waste quantity, thereby space required for landfills is decreased and provides additional energy sources from ignition (Ornebjerg et al., 2006). The Incineration of MSW produces flue gases such as Carbon Dioxide (CO₂), Carbon Monoxide (CO), Particulate Matter (PM), HCl, Sulphur Dioxide (SO₂), Nitrogen Oxide (NO), total organic carbon, Hg and its compounds (Alba et al., 1997; Quinaa et al., 2008). The burning of coal, coal processing waste and coal derivatives has produced various gas emissions, especially nitrogen and sulfur oxides are harmful. The percentage of harmful gases depends on the composition and concentration of coal, water, and flammable liquid. The results indicate that coal mixed with water produces fewer gas emissions compared to coal (Margarita et al., 2018). ESP has been utilized to remove emissions such as particulate matter, nitrogen oxide (NO), and carbon monoxide from the diesel exhaust (Phirun et al., 2012). Suppose the particulate matter in harmful gases is released into the atmosphere without a filtration system. In that case, it could cause climate change, affect human health, and also cause lung diseases and bronchitis. Generally, an Electrostatic precipitator is one of the devices to purify the fine dust particles and smoke from flue gases. It has high collection efficiency, low energy consumption and pressure drop (Kim et al., 2001; Remaoun et al., 2014; Patino et al., 2016). In ESP, the high voltage power supply requires a range of 15 to 100kV for effective ultra-fine dust particle collection from flue gases (Grasset al., 2004; Shafiei et al., 2013; Slobodan et al., 2016). Researchers worldwide have published many articles pertaining to the augmentation of collection efficiency of ESP based on discharge electrode shape, material, inter discharge electrode distance, the distance between collecting plate and discharge electrode, and other parameters. The filtration efficiency of ESP has been investigated for different discharge electrode positions using aerosol spectrometer GRIMM 1.109, which measures the particle concentration with a measuring range of 0.25 to 32 µm. The obtained results clearly indicate that position of the discharge electrode and

polarity of DC voltage play a vital role in collection efficiency (Niewulis et al., 2011). The electrical characteristics of wire-plate ESP, which is a function of discharge electrode geometry, inter discharge electrode distance, and the number of discharge wires, have been analyzed. The results have proved that electrical characteristics and ESP filtration efficiency are enhanced by reducing the collecting plate distance without increasing applied voltage (Khaled and Eldein, 2013). The collection efficiency, which is the ratio of dust particles deposited on the collection electrode and total dust particles entered into the ESP. Design of ESP requires accurate calculation of collection efficiency, which in turn requires total collection area, gas flow rate and dust particle migration velocity. The researchers investigated the important parameters for an ESP, which includes the shape of the discharge electrode, distance between two discharge electrodes, and discharge wire to collecting plate spacing, gas flow rate, and applied voltage at the discharge electrode (Narendra Gajbhiye et al., 2015). The simulation for two types of ESP, (i) ESP with Spike discharge electrode and, (ii) ESP with wire discharge electrode to investigate the particle collection efficiency and other geometries in the two types of ESP remain unchanged. High Voltage DC is applied to the spike electrode thereby corona is produced at the spike tips (S. Arif et al., 2016). Needle-plate electrostatic precipitator by changing design parameters such as radius of the needle tip, distance between needle and plate, applied voltage to the needle and temporal characteristics of trichel pulses. Needle-plane distance varies from 6 mm to 3 cm, radius of the needle varies from 19mm to 55mm and applied voltage varied from -4kV to -10kV. The DC corona current and frequency of trichel pulse increases by increasing applied voltage and decreases by increasing needle-plate distance (Peyman Dordizadeh et al., 2016). The Comsol Multiphysics simulation for the gas flow (fluid dynamics) part is based on the Navier-stokes equation. For small diameter particles, the drag force is corrected by Cunningham correction factor, the second important force acting on the dust particle is Coulomb force which is based on the electric field and charged particle (Donato Rubinetti et al. 2015). The Electrostatic Precipitator collection efficiency is based on the gas flow rate, size of the precipitator, and particle migration velocity which is given by Deutsch-Anderson equation. The Reynolds number is a dimensionless number which helps to predict the fluid flow patterns. It is defined as the ratio of inertial force and viscous force. If the Reynolds number is less than or equal to 2000 then the flow is laminar. If the Reynolds number value is between 2000 to 4000 then the flow is transitional. If the Reynolds number value is greater than 4000 then the flow is turbulent (Dang Xiaoqing et al.). There are two ways of increasing the collection efficiency of ESP are (i) increase the dust particle migration velocity by maximizing the electric field strength around the discharge electrode (ii) by decreasing the gas flow rate (Octavian Blejan et al., 2007). The corona discharge electrode ESP is suitable to remove diesel exhaust particles. Still, it has low filtration efficiency for Nitrogen Oxide (NO). The barrier discharge electrode-based ESP is suggested to improve filtration efficiency for Nitrogen oxide (NO) as well as diesel particulate matter. The discharge electrode is made up of aluminum plates with a thickness of 0.5mm, and collecting plates are made up of glass. The experimental analysis is carried out with the help of Particle counter (RION model KC-01B, C) for barrier discharge electrode with and without the punched hole. The ESP Efficiency is determined based on the operating time, discharge power, and applied voltage. The results have been validated. It is found that the filtration efficiency of ESP is higher for large diameter punched electrodes than plane electrodes, and small diameter punched electrodes (Kuroda et al., 2003). The ESP filtration efficiency is enhanced with the help of foam-covered collecting electrodes. Dust Particles coming into the pores have not easily returned to the atmosphere, and also it reduces the pre and post filter in the ESP. The particle counter (Haltech HPC600) has been used to count the dust particles at ESP outlet, and the experiments have been carried out for different airflow velocities i.e. 0.5 m/sec to 2.5 m/sec. The results have been validated and found that foam-covered collecting plates in ESP have higher collection efficiency and moderate airflow velocity, suitable for capturing small dust particles (Wen et al., 2015). Collection Efficiency of ESP has been analyzed based on the concentration of particles and found that high efficiency is achieved when inlet particle concentration ranges from 200mg/Nm³ to 3600mg/Nm³ (Arif et al., 2018). A wet dust removal system (WDRS) has been developed by using wet phase transition agglomerator (WPTA) and wet electrostatic precipitator (WESP). In a Coal-fired power plant, the emission of particles has reduced to less than 5 mg/m³ with the help of WDRS. The results clearly indicate that the filtration efficiency of the WESP has been increased by increasing the applied voltage (Cao et al., 2017). The removal of flue gas emission from Incinerator has been carried out in two ways (i) using

after burners (ii) using a combined system. The experimental results clearly show that the concentration of dioxins (PCDDs + PCDFs) at inlet and outlet of after burner is 66.1 ng-TEQ/Nm^3 and $0.213 \text{ ng-TEQ/Nm}^3$, respectively. Further, the efficient dioxin decomposition has been achieved with the gas temperature greater than 850°C . The combined wet type ESP system, scrubber, and radiator successfully remove gaseous pollutants and dusts such as dioxins (PCDDs + PCDFs) and HCl for a large range of initial concentrations. Besides, this system achieves more than 90% efficiency in any case of initial concentration (Kim et al., 2000). The elimination of $\text{PM}_{2.5}$ particles has been done by using lab-scale two-stage electrostatic precipitator with precharge and parallel collecting plates. The analysis of collection efficiency for two-stage ESP is conducted with Alternating Current (AC) and DC voltages and found that $> 96\%$ and $> 90\%$ efficiency has been attained when the precharger was energized by DC and AC voltages, respectively (Jaworek et al., 2017). The flue gas cleaning method has been conducted using eight different Air Pollution Control (APC) technologies from no treatment to the most modern APC technology and found that wet flue gas cleaning, semidry flue gas cleaning and dioxin filter followed by flue gas condensation and Selective Catalytic Reduction (SCR) have provided the finest flue gas emission control mechanism. Apart from this, Electrostatic Precipitator and Fabric filter provides better removal efficiency ($> 95\%$) for small and large particle size (μm) compared with cyclone and low-pressure venturi scrubber (Vehlow et al., 2010). The removal of particulate matter from a small waste incinerator's exhaust gas has been achieved with the pilot-scale ESP with the sizing of (1000mm*10000mm*1000mm). The results clearly indicate that 100% collection efficiency has been achieved with the particles larger than 400 nm (Intra et al., 2014). Hence considering the above facts, the intention of this paper is to design a cost-effective Photo-Voltaic powered Needle-plate Electrostatic Precipitator with dimensions (900mm*250mm) to filter the fine dust particles and smoke from flue gases produced by incineration of MSW.

2. Materials And Methodology

The needle-plate ESP has been preferred in this work because it can handle a higher gas flow rate and produce high electric field strength around the discharge electrode compared to other ESP types. The schematic diagram of the entire experimental setup is depicted in Fig. 1. The experimental setup consists of three parts such as (i) Power Supply to the Electrostatic Precipitator, (ii) Electrostatic Precipitator, (iii) Municipal Solid Waste Incinerator. In the Power Supply Part, a 250Wp PV module with maximum power point voltage (V_{mpp}) of 37.15V and maximum power point current of 7.29A was given to the solar power conditioning unit, which consists of DC-DC Boost Converter and Voltage Source Inverter.

The DC voltage from the solar panel was stepped up and regulated by DC-DC Boost Converter, and the FGA25N120AN IGBT has been utilized in the inverter circuit to convert DC link voltage into AC with the switching time of 20 milliseconds. The 230V AC power supply is given as input to the T-R set, which converts 230V AC into (5–80) kV variable DC with the help of an electronic controller which is designed to adjust the output voltage and current of T-R set. The Electronic controller circuit consists of DSPIC33FJ128GP710A microcontroller, anti-parallel thyristors, voltage sensor, and current sensor. By adjusting thyristors' duty cycle, the primary winding voltage is varied, and thereby, secondary winding voltage is changed accordingly. The negative terminal of the T-R set is connected to the discharge electrode of the electrostatic precipitator, whereas the positive terminal is connected to the collecting plate, and it is grounded. The dimension of the Proposed Needle-Plate Electrostatic Precipitator is given in Table 1.

Table 1

Design parameters and its values of the proposed Electrostatic Precipitator

Design Parameters	Values
Gas Flow Rate	0.56 cu.m/sec
Pressure Drop	20 mm of WG
Temperature	150 ⁰ C(max)
Inlet and outlet diameter of the ESP	200 mm
Length of the collecting plate	1830 mm
Breadth of the collecting plate	1735 mm
Distance between two collecting plates	200 mm
Radius of the discharge electrode	0.75 mm
Distance between discharge electrodes	200 mm
Distance between discharge electrode and collecting plate	100 mm

The discharge electrode is made up of stainless steel (SS 302), which has higher carbon than other grades and does not corrode easily. The Collecting Plates, Carcass of ESP, inlet, and outlet duct is designed using mild steel. The collecting plates are connected to the outer structure of the Electrostatic Precipitator, and it is earthed. The discharge electrodes are connected to the high voltage power supply, and it is isolated from the ESP body using a Teflon insulator. High Voltage DC is slightly varied from 5kV, and the negative gradient of the electric field is also increased accordingly. When applied voltage attains the corona onset voltage, Corona current starts flowing from discharge electrode to collecting plate which ionizes the flue gases produced within a specially designed Incinerator by burning MSW. Liquefied Petroleum Gas (LPG) has been used as fuel in the incinerator. Exhaust Fan is located downstream of the ESP to collect the flue gas from incinerator through Electrostatic Precipitator. The experimental setup entire system is depicted in Fig. 2. Flue gas analysis has been performed at ESP inlet and outlet using stack sampler and flue gas analyzer. The sampling process has been conducted for thirty minutes. The sampling porthole has a diameter of 76.2 mm, which helps to place the gas analyzer probe and sampling thimble from the stack sampler.

3. Results And Its Discussion

The magnitude of the V_{DC} limit has been manually set in the electronic controller. It clearly indicates that ESP voltage is varied based on the transformer primary winding Voltage. The transformer rectifier's output voltage has been reached 78.9kV DC for the transformer primary winding voltage of 199 V AC. The current-voltage characteristic of the developed Electrostatic Precipitator is depicted in Fig. 3.

The flow chart depicts the system boundary for the filtration efficiency of ESP analysis (Fig. 4). The DC voltage applied to the Electrostatic Precipitator can be controlled from the electronic controller of the Transformer-Rectifier (TR) set.

The corona current has started at the corona inception voltage of 10kV; after that, it has been varied linearly with applied voltage. The electric field intensity has been analyzed numerically for ESP with different distances between needle and collecting plate. It clearly indicates in the Fig. 5 that impact of varying distance between the needle electrode and collecting plate (a) has changed the magnitude of electric field intensity. An electric field's strength is high at the tip of the needle, and it decreases as distance increases from the discharge electrode to the collecting plate.

The filtration efficiency of ESP is mainly based on electric field intensity, and thereby high efficiency is achieved with a smaller distance between the needle and collecting plate. Thus, a 0.1m distance has been maintained between needle-type emitting electrode and collecting plate in this work. The Poissonian electric field has been applied to describe Fig. 6, which is given in Eq. (1)

$$\nabla \cdot \mathbf{E} = \rho / \epsilon_0$$

1

Where E- Electric Field Intensity, ρ -Space Charge Density, ϵ_0 - relative permittivity. The collection efficiency for different particle diameter concerning to applied voltage is depicted in Fig. 6. From the graph, we can observe that particle collection efficiency is 65% for the applied voltage of 24kV with the particle diameter of 5 μ m. However, with the same applied voltage, the particle collection efficiency is 55% and 41% for the dust particle diameter of 3 μ m and 2 μ m, respectively. Thus, the collection efficiency of the ESP is directly related to the diameter of the dust particle. Further, with the help of the graph, we can conclude that the collection efficiency of ESP is increasing with respect to the applied voltage.

A stack sampler is used to collect the gas from the inlet and ESP outlet to measure the PM concentration. After the gas is collected, PM concentration is obtained by using the weight of a sampling thimble. The mathematical calculation of PM concentration is represented in the Eqs. (2) and (3)

$$\text{PM}(\text{mg}/\text{Nm}^3) = ((A - B) * 10^6) / C$$

2

$$C = (E * T) / D$$

3

Where A-Initial weight of the thimble, B-Final weight of the thimble, C = Air volume in m³, E-Volume of Liters Per Minute (LPM), D-Volume of air in liters, T-Sampling time. The Flue gas analyzer measures the CO, NO in parts per million. The Conversion of parts per million into mg/Nm³ is given in the Eq. (4)

$$\text{mg}/\text{Nm}^3 = \left(\frac{\text{PPM} * \text{M}}{\text{D}} \right) * \left(\frac{\text{P}}{\text{P}_0} \right) * \left(\frac{\text{T}}{\text{T}_0} \right)$$

4

Where PPM-Parts per Million, M-Molecular weight, P-Sea level pressure, T-Stack temperature, Standard pressure (P_0)-760 mm Hg, and Standard temperature (T_0) - 273.15 K. Several countries have framed rule books enclosing information for emission standards. **Table. 2** clearly indicates that all parameters at the ESP outlet fall within the emission standards laid down in the SWM rules book by the Ministry of Environment, Forest, and Climate Change, Govt. of India [25] and the statistical analysis of Particulate Matter, Carbon Monoxide, and Nitrogen Oxide have been done with error assessments.

Table 2

Test report of flue gas analysis at ESP inlet & outlet with error assessments and emission standards

S. No	Parameters	ESP inlet	ESP outlet	Emission standards provided in the Solid Waste Management rules book
1	Particulate Matter	76.15 ± 2mg/Nm ³	3.7 ± 1 mg/Nm ³	50 mg/Nm ³
2	Carbon Monoxide	185 ± 2mg/Nm ³	91.3 ± 2mg/Nm ³	100mg/Nm ³
3	Total Organic Carbon	8 ± 2 mg/Nm ³	3.21 ± 2 mg/Nm ³	20 mg/Nm ³
4	Nitrogen dioxide	56 ± 2 mg/Nm ³	4.89 ± 2 mg/Nm ³	400 mg/Nm ³

The flue gas emission test has been done for the concentration of Particulate Matter((PM2.5 &PM10) at Electrostatic Precipitator outlet. The obtained results were 28 mg/Nm³ & 31 mg/Nm³ (Fig .7), which are found to be a little amount, and the permissible Emission standards provided in the Bio-Medical Waste Management rule book is 50mg/Nm³.

Further, the filtration efficiency of ESP has been validated with the polyester filter samples, which are fixed upstream and downstream of the ESP, and it is depicted in **Fig. 8(a, b)**. As anticipated, the color of the filter sample used to capture the smoke particles, alter depending on their location. The filter sample has been recovered a large quantity of dust particles before the ESP, which considerably changes its color. After the ESP, the filter sample color is not changed because the dust particles are deposited in the Collecting plate of ESP. The Collecting Plate after gas treatment is shown in Fig. 8c. It is noticed that a large amount of smoke particles are deposited in the plate after the ESP operation.

In addition to the experimental investigation of ESP, a CFD Modeling has been done to analyze the dust particle charging and its collection process in Electrostatic Precipitator. Numerical calculations were conducted for various applied voltages in the range of 45–90 kV and various particle diameters in the range of 2µm-5 µm. The temperature and pressure were 293 K and 1 atmosphere, respectively. The dust particles with different diameters are entered into the Needle-Plate ESP inlet, and then it is charged and deposited on the collecting plates by an electrostatic field. In this case, 180 dust particles are entered, and then the performance of needle-plate ESP is analyzed for different applied voltage and particle diameters.

Table 3
Comparison of dust particle entered and escaped with various diameter and applied voltage

Applied Voltage	2 μ m dust particle		3 μ m dust particle		5 μ m dust particle	
	Number of Particles Entered	Number of Particles Escaped	Number of Particles Entered	Number of Particles Escaped	Number of Particles Entered	Number of Particles Escaped
-30kV	180	172	180	163	180	94
-45kV	180	153	180	118	180	0
-60kV	180	128	180	20	180	0
-75kV	180	87	180	0	180	0
-90kV	180	21	180	0	180	0
-95kV	180	6	180	0	180	0

With the help of Table 3, we can conclude that the performance of Needle-Plate ESP is excellent for large particle diameter with high applied voltage.

The collection efficiency of the proposed needle-plate type Electrostatic Precipitator is high compared to the other two methods. Compared with existing methods, the proposed method utilizes renewable energy sources; thereby, no external power supply is required.

Table 4
Comparison of developed work with two other methods

Dimensions and Operating conditions	Work 1	Work 2	Developed Work
Type of ESP	Wire-Tube type	Wire-Plate type	Needle-Plate type
Number of Plates/Tubes	19	10	7
Number of discharge electrodes	19	10 per row	54
Discharge electrode diameter	2mm	3mm	1.5mm
Height or length of the collecting electrode	400mm	1000mm	1830 mm
Distance between collection plate to discharge electrode	10.77 mm	50mm	100mm
Distance between discharge electrodes	-	50mm	200mm
Operating Voltage	6-8kV	20kV	55kV
Collection Efficiency	~ 70	~ 80	~ 86.7
Source for Power Supply to the ESP	220V AC power supply	220V AC power supply or 12V Battery or solar cells	Solar power with backup 12V batteries
Reference	(Intra et al., 2010)	(Intra et al., 2014)	-

4. Energy And Cost Savings In Comparison To Conventional System

The emissions or waste from the electricity produced by Solar panels would be zero (**Table. 5**). In contrast to, fossil fuels, power plants, Solar Panel can produce clean and renewable energy without locating, excavation, transportation, or combustion. It's a simpler, cheaper, cleaner, and all-around better energy solution.

Table 5
Comparison of conventional and solar powered ESP

	Conventional Electricity to ESP	Solar Powered ESP
Fuel Sourcing	Fossil fuels must be situated, digged out and transported before it came to the usage. These activities would make the land most instability.	Energy from the sun is harmless and free. It can be harnessed and converted into power anyplace a solar panel can be installed.
Power Generation	Fossil fuels need to be burned to produce electricity, it would make air pollution and other environmental damage	Solar can produce power without emissions and waste.
Cost of Consumer Electricity	Total number of Units required by developed Electrostatic Precipitator per day: 4.8 Total number of Units required per year: 1752 Total number of Units required for 25 years: 43800 EB cost for 1 unit in India: Rs.6 EB cost for total number of units required for 25 years: Rs.262800	Total Amount Spent for 1000Wp Solar power with four backup batteries and solar power conditioning unit: Rs. 1,72,000 Total Savings: Rs.90800 (Rs.262800- Rs. 1,72,000)
The Human Element	The availability of Fossil fuels has been decreasing over the years. It can lead to labor strikes, price volatility, and even war.	The availability of Solar energy is abundant and it will be accessible for another 5 billion years
Transformer-Rectifier	(i) The 50Hz Transformer-Rectifier set is large and it would produce voltage ripples in the range of 30 to 40% of output DC voltage. It requires more time to treat the dust particle coming out of Electrostatic Precipitator.	(i) High frequency transformer operated with 20 KHz to 1MHz. Size of this transformer is less and it would produce small ripple in the output DC voltage. HF Transformer –Rectifier provides higher and average power supply into the ESP thereby time needed to treat a particle can be much shorter. This in

5. Conclusion

This proposed article has identified the potential ways to design and implement cost-effective solar-powered electrostatic precipitators for the filtration of flue gases from Municipal Solid Waste Incinerators. The ESP has been energized by solar energy with power electronic converters and a high voltage T-R set. The flue gas analysis of ESP has been carried out with a stack sampler and flue gas analyzer. The obtained results for particulate matter, carbon monoxide, and other flue gases have been validated and found that it falls within the required emission standards. Further, the collection efficiency of ESP has been validated with a polyester filter sample. Near future, we planned to conduct flue gas analysis for all the major pollutants released from the incineration of Municipal Solid Waste (MSW) with the help of pilot-scale ESP with the dimensions of (2740 mm x 1310 mm).

Declarations

Competing interest

The authors declare that there is no competing interest

Availability of data and materials

Not Applicable

Ethical Approval

Not Applicable

Consent to Participate

Not Applicable

Consent to Publish

Not Applicable

Authors Contributions

Conceptualization, Methodology, Resources, Formal analysis and investigation were carried out by Anandhraj Pannerselvam, Mohana Sundaram Kuppusamy, Jayaraman Shanmugapriyan, Vishnu Kumar Kaliappan, Ravishankar Sathyamurthy

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Figures

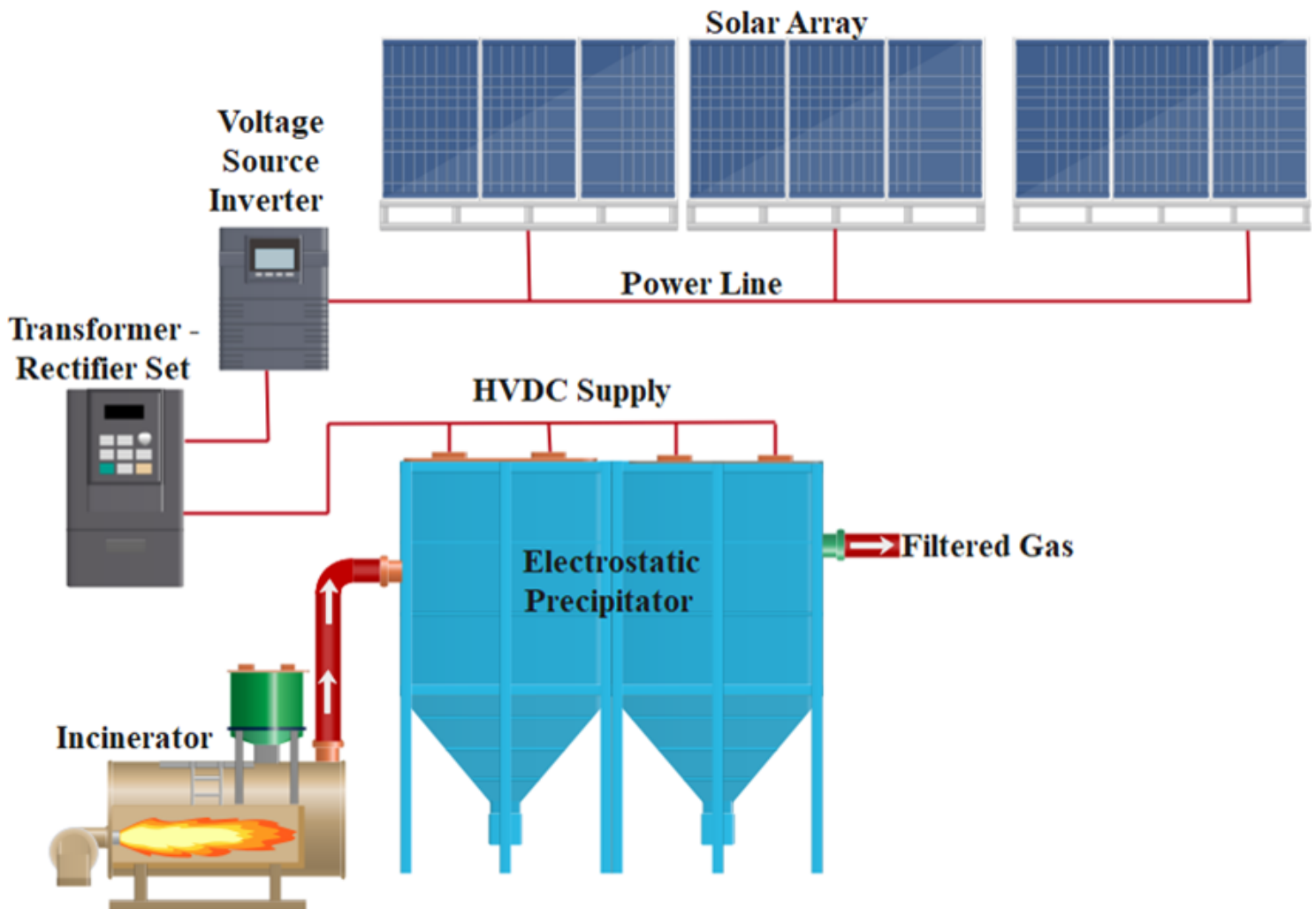


Figure 1

Schematic diagram of the experimental setup

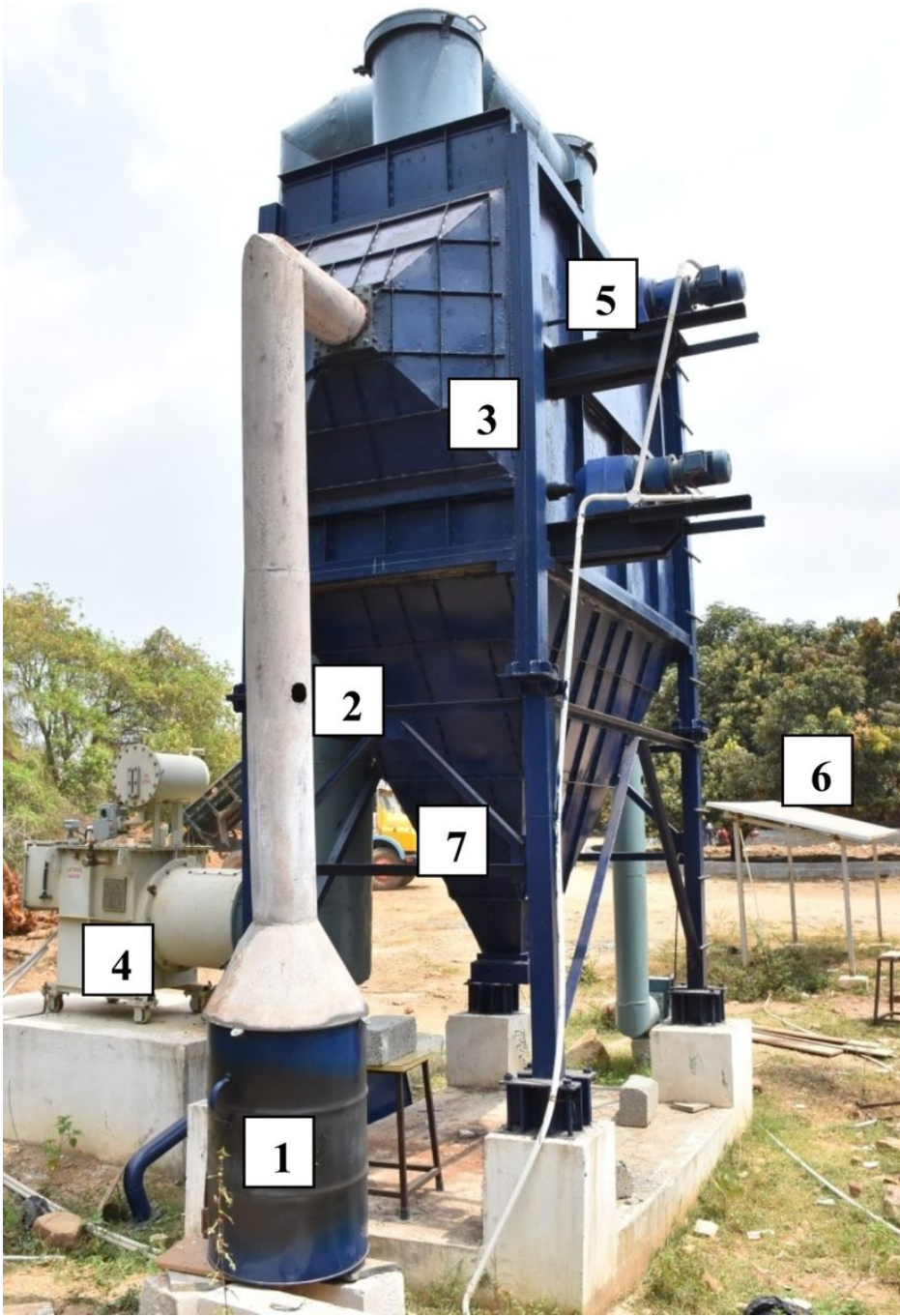


Figure 2

Experimental Set-Up. 1- Incinerator 2-Sampling Port Hole 3-ESP 4-TR Set 5-Rapper Motor 6-PV Array 7-Hopper

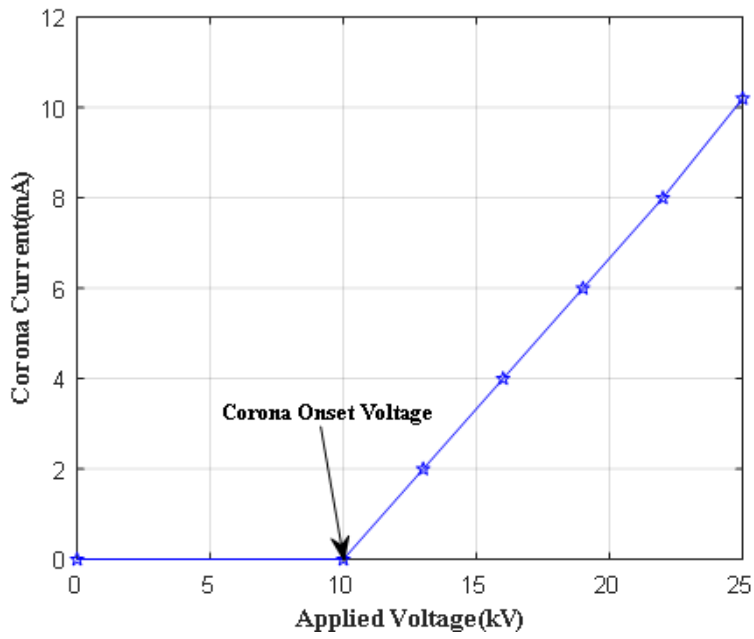


Figure 3

Voltage-Current characteristics of ESP

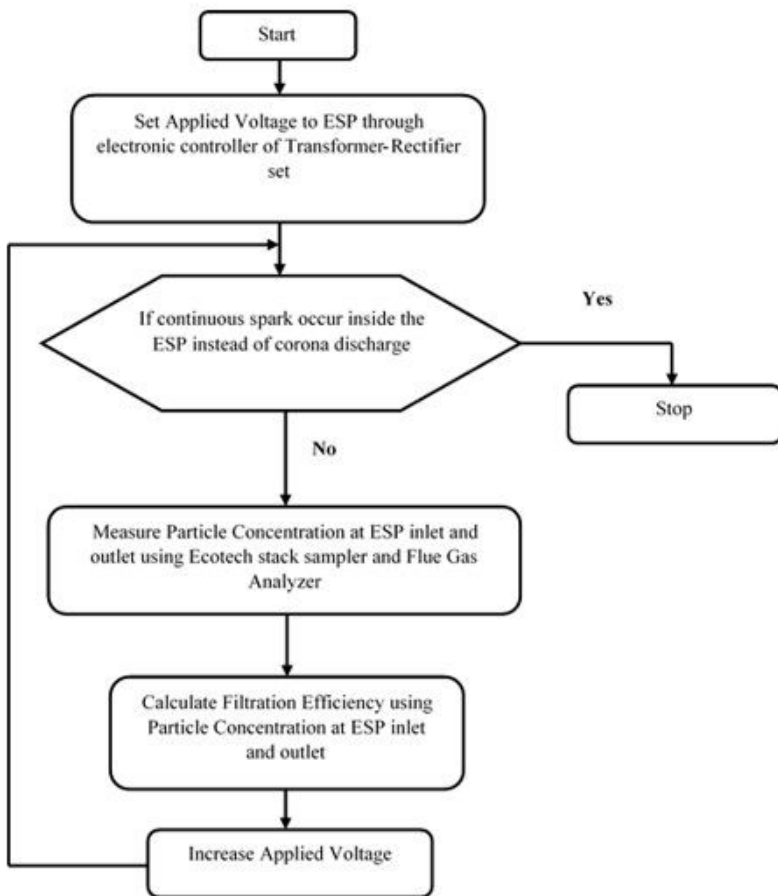


Figure 4

Flowchart for the filtration efficiency of ESP analysis

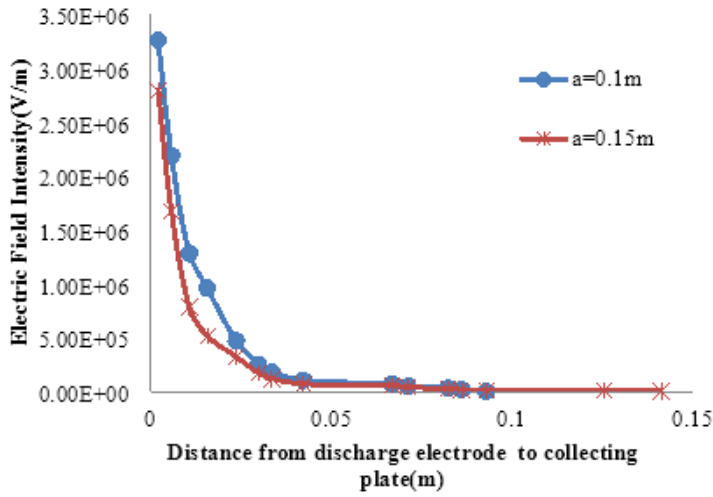


Figure 5

Electric Field Intensity as a function of the distance between the discharge electrode and the collecting plate.

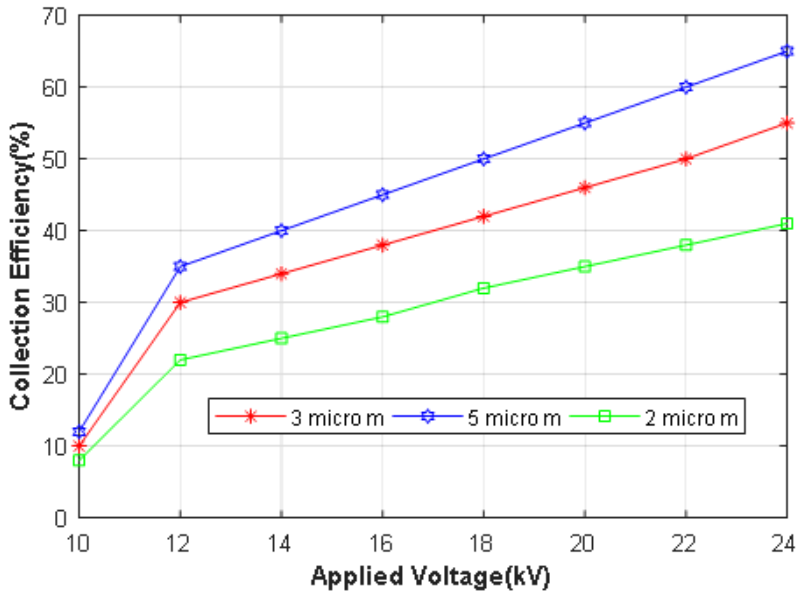


Figure 6

Influence of the voltage applied on the collection efficiency



Figure 7

Particulate Matter (PM2.5 & PM10) at ESP outlet



(a)



(b)



(c)

Figure 8

(a, b) Polyester Filter Samples before and after the ESP, (c) Collecting plate after gas treatment in ESP