Removal of Particulate Matter from the Emission Gas of a Small Incinerator using a Small-Scale and Uncomplicated Electrostatic Precipitator

Panich Intra[*1], Artit Yawootti[1], Visut Asanavijit[2], and Nakorn Tippayawong[3]

[1] College of Integrated Science and Technology, Rajamangala University of Technology Lanna, Chiang Mai, Thailand 50300

[2] Department of Electrical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai 50200

[3] Department of Mechanical Engineering, Chiang Mai University, Chiang Mai, Thailand 50200

* Corresponding Author: Tel: 053 266 523, Fax: 053 266 523,

E-mail: panich_intra@yahoo.com

Abstract

Incineration is conceptually sound and as a waste treatment technology. There is, however, concern over its air emission when it is improperly designed and operated. An electrostatic precipitator is one of the most commonly used devices to control particulate emissions from boilers, incinerators and some other industrial processes. To test this idea, a small-scale and uncomplicated electrostatic precipitator for the removal of particulate matter from the exhaust gases of a small incinerator was developed and investigated. The size of the precipitator was 1,000 mm (W), 1,000 mm (H), 1,000 mm (L) and it was equipped with corona discharge wires. The corona discharge wires were connected to a positive high-voltage pulse generator, while the collection plates were grounded. The high-voltage pulse generator was used to produce the corona discharge field between the individual discharge wire and the collection plate. The particulate-laden exhaust gas flow was directed across the corona discharge field. The charged particles were deflected outward and collected on the collection plate wall. The precipitator collection efficiency was evaluated as a mass loading ratio between the difference at the inlet and the outlet, to the particulate loading at the inlet of the precipitator. The collection efficiency of this small-scale and uncomplicated electrostatic precipitator design was found that approximately 80 %.

***Keywords**:* Particle, Particulate Matter, Electrostatic Precipitator, Biomass, Incinerator

1. Introduction

A one of the most common devices used successfully to remove suspended particulate matter from the emission gas in refuse incineration is an electrostatic precipitator (ESP) [1 – 4]. Jaworek et al. [3] review its recent development. Its principle is to separate particulate matter from an exhaust gas by corona charging the particulate matter and driving them toward the collection plate using electrostatic forces. The ESP has the advantage that it can be operated over a wide range of gas temperatures from ambient to 850 ^{o}C, it can achieve high collection efficiency of above 99%, its construction is robust and reliable, and it requires low maintenance [2].

However, an ESP with high removal efficiency normally is large in size, suitable only for industrial applications. Also, it can be complicated and very expensive to operate. There have been several studies and developments on ESP applied to exhaust after-treatment system of biomass furnaces. Most published reports are limited to the characteristics of ESP in large-scale applications [1 – 4]. Little has been said on the installation of this pollution control device in small-scale biomass fired furnaces [5 – 6]. Affordable and practical technology is not available for small incinerator systems.

The present study is an attempt to fill this gap. The work focuses on design, construction, and test of an uncomplicated, compact and cost effective ESP capable of removing particulate matter from the stack gases of a small municipal incinerator.

2. Design of the Small-Scale and Uncomplicated ESP

An ESP is needed to remove the particulate matter from the emission gas of an incinerator. The primary performance requirements of the ESP are dictated by size range and mass concentration of particles as a whole: particulate size range from 10 nm – 10 μm and particulate mass concentration at the outlet of the ESP should have less than 15 μg/m3. Generally, the ESP must be safe to use and have low maintenance requirements. Fig. 1 shows a schematic diagram of the small-scale and uncomplicated ESP. It consists of four major components: a gas inlet tube, a particulate collector, a clean gas outlet tube, and a high voltage power supply. The following paragraphs give a brief description of the rationale and design of these components.

2.1 Particulate collector

In the present study, a wire-to-plate ESP configuration was used for the particulate collector. This configuration was considered because it has collecting plates that are easy to clean. The schematic of the particulate collector is shown in Fig. 2. The total dimension of the precipitator was 1,000 mm × 1,000 mm × 1,000 mm and it was equipped with corona discharge electrodes. The discharge electrodes are made of a stainless steel rod, 2 mm in diameter and 1,100 mm in length.

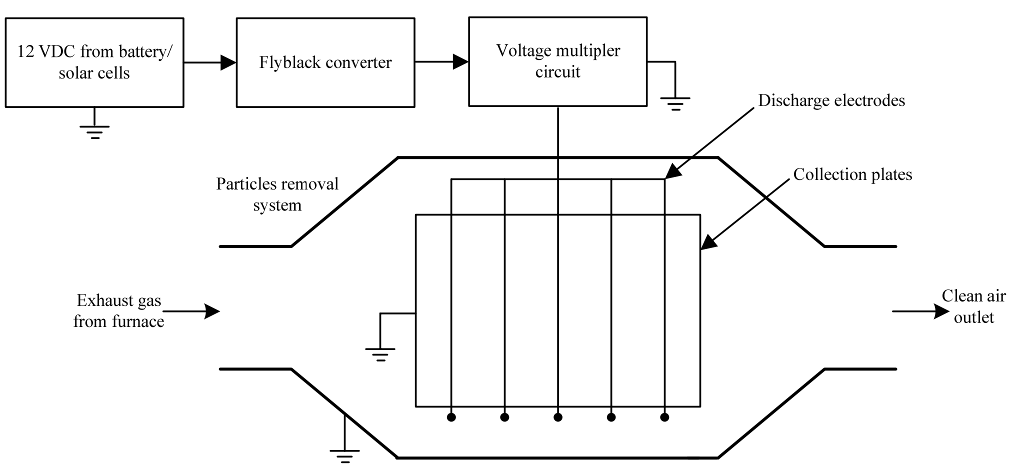

Fig. 1. Schematic diagram of the small-scale and uncomplicated ESP.

Fig. 2. Picture of the present particulate collector.

The ten collection plates are made of steel, 1,000 mm in height × 1,000 mm in width × 3 mm in thick. The distance between the discharge electrode and the collection plate is approximately 50 mm, and the distance between the discharge electrodes is approximately 50 mm. The primary hazard arising from the collector itself, this is due to the high voltage applied to the corona discharge electrodes in order to create a strong electric field within the ESP. The high voltage hazard can be minimized by properly insulating all high voltage lines and connections, isolating any exposed components, and by using insulation materials with sufficient dielectric strength to prevent arching and short-circuiting. The corona discharge electrodes were connected to a positive high voltage pulse power supply, while the collection plates were grounded. The high voltage pulse power supply was used to produce the corona discharge field between the individual discharge electrodes and the collection plates. The charged particulates were then deflected outward and collected on the collection plate wall. Collection efficiency of the ESP is defined as the ratio of the difference between inlet and outlet concentrations to the inlet concentration. Uniform particle distribution was assumed across the collector. The particle removal efficiency of the ESP, η , for a given particle size could be estimated by Deutsch-Anderson equation as [7]

$$\eta = 1 - \exp\left(-\frac{v_p L}{us}\right) \qquad (1)$$

$$v_p = \frac{n_p e E C_c}{3\pi\mu d_p} \qquad (2)$$

where v_p is the particle velocity, L is the length of the collection plate, u is the gas velocity, s is the wire to plate distance, n_p is the net number of elementary charges on the particle as a function of particle diameter, e is the value of elementary charge on an electron, E is the electric field, C_c is the Cunningham correction factor, and μ is the gas viscosity, and d_p is the particle diameter.

2.2. High voltage power supply

A high voltage power supply was used to generate high electric field strength between collecting plates and discharge electrodes. In this study, a high voltage, pulsed, positive power supply was used to apply varying impulse peak voltages and impulse frequencies to the corona discharge electrodes.

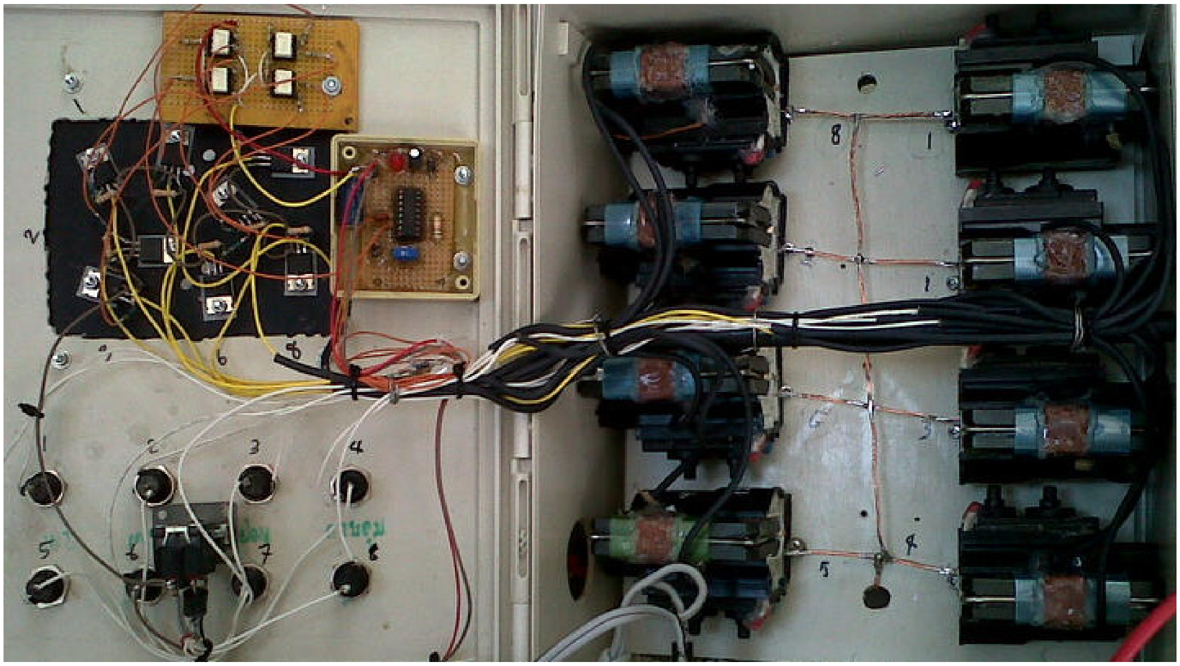

Fig. 3. Picture of the high voltage positive pulsed power supply.

The pulsed power supply had many advantages when compared with the conventional DC high voltage: higher peak voltage without excessive breakdown, and therefore better particle charging [8]. A simple flyblack converter was used to DC/DC conversion from 12 VDC to 20 kVDC. It is equivalent to that of a buck-boost converter, with the inductor split to form a transformer. Fig. 3 shows a picture of the high voltage positive pulsed power supply. The supply consisted of an input DC voltage power supply, a PWM (pulse width modulated) generator, a power MosFET, a high voltage transformer, and a high voltage diode. This power supply can produce an output high voltage of 20 kV, output current of about 280 μA, and pulse frequency of about 30 kHz.

3. Experimental Setup

The experimental setup for the particulate collection measurements is shown in Fig. 4. A small-scale municipal incinerator of 1 ton per day was used to determine the particle collection efficiency of the experimental ESP. It could be operated continuously under stable working conditions for several hours. The temperature of the emission gas entering the ESP was about 100°C, while the combustion temperature ranged from 500 – 700 °C, and the pressure was 1 atm. A temperature drop of 400 – 600 °C occurred in the 5 m long pipe between the incinerator outlet and the ESP. The exhaust particulate matter from this incinerator passed through the ESP. Measurements of the particle concentrations upstream and downstream of the ESP were performed by the gravimetric method. For particulate sampling, an isokinetic tube was used to measure the concentration of the particulates. The measuring points were positioned at the center of the cross section of the inlet and outlet of the ESP.

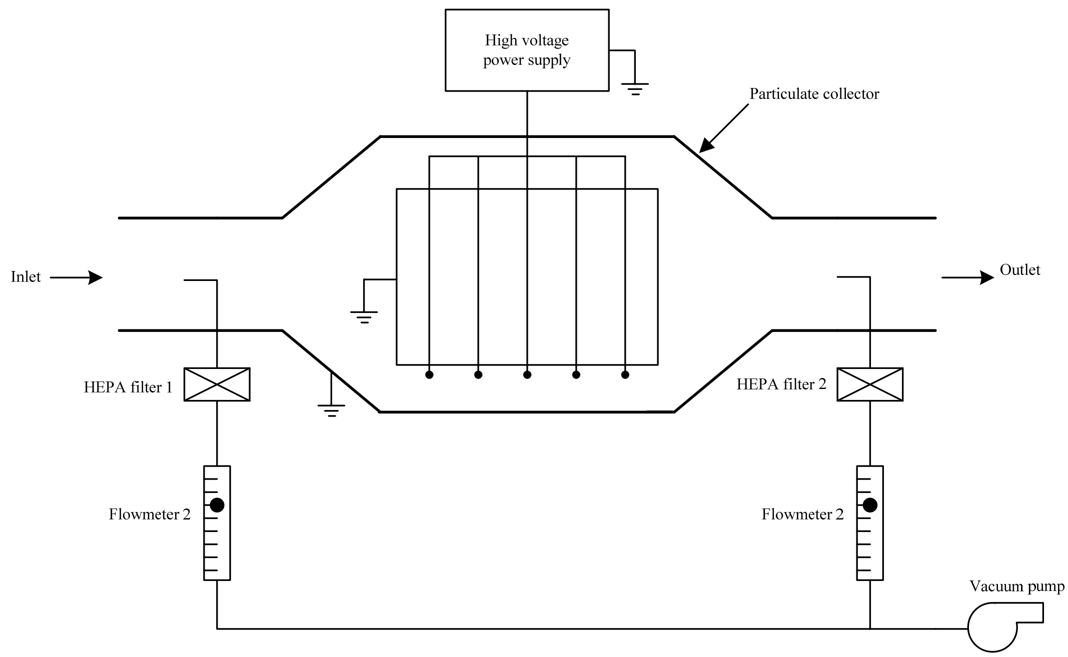

Fig. 4. Setup of the experimental system.

Particulate sampling the flow was regulated and controlled by means of a mass flow meter and controller, typically at 5 L/min. The particulate sampling time was about 15 min. Thus, the overall collection efficiency of the ESP was evaluated with the mass loading of the particles collected by the high efficiency particulate filters (HEPA) (Whatman model EPM 2000) at inlet and outlet of the ESP. This efficiency is given by [4]

$$\eta = 1 - \frac{m_{\text{outlet}}}{m_{\text{inlet}}} \qquad (3)$$

where m_{inlet} is the mass loading of particulate matter at the ESP inlet, and m_{outlet} is the mass loading of particulate matter at the precipitator outlet. The basic operating conditions of the municipal incinerator and the parameters used for the calculations are shown in Table 1. For each set of operating conditions, measurements were repeated a minimum of three times.

Table 1. Operating conditions of the municipal incinerator.

Operating conditions	Values
Gas flow rate	15 L/min
Gas temperature	413 K
Pressure	1 atm

4. Results and Discussion

Fig. 5 shows the variation of collection efficiency with particle diameter at different operating corona voltages. Deutsch-Anderson equation for wire-to-plate type collectors (Equation 1) was used to calculate the collection efficiency of the ESP. The data presented covers particulates size in the range between 0.01 μm – 100 μm. An increase in corona voltage produced an increase in collection efficiency of the ESP. An one hundred percent collection efficiency was found for a corona voltage of 25 kV for all particles larger than 10 μm.

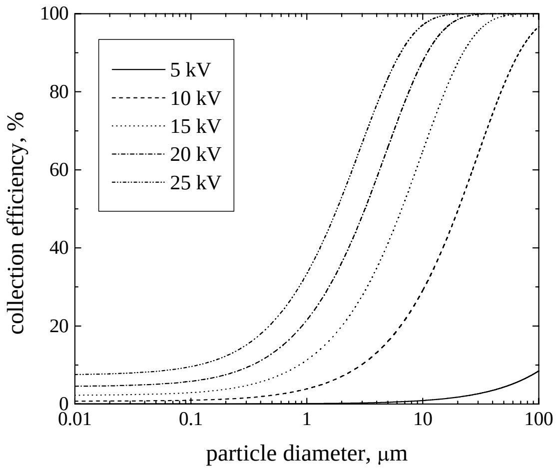

Fig. 5. Variation of collection efficiency with particle diameter at different operating corona voltages

(a) Inlet (b) Outlet

Fig. 6. Typical particulate collected on the HEPA filter at the inlet and outlet of the ESP at 25 kV.

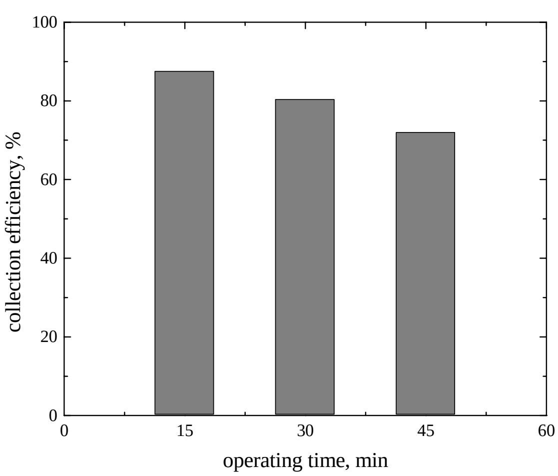

Fig. 7. Variation of collection efficiency with operating time at corona voltage of 25 kV.

The efficiency decreased to about 10 % at 30 nm in diameter. It is very difficult to effectively collect particles below this size. Fig. 6 shows the typical particle collection on the HEPA filter at the inlet and outlet of the ESP for a corona voltage of 25 kV. It was shown that the particulate mass was 67.5, 72.4, and 63.1 mg, respectively for each sampling at the inlet, and the particulate mass at the outlet was 56.7, 60.0, and 59.4 mg, respectively for the same sampling. For these numbers, the collection efficiency of was 87.61, 80.41, and 72.05%, respectively for each of the samplings of the inlet as compared to the outlet of the ESP. However, a drop in collection efficiency was observed after a prolonged period of operation (Fig. 7.). It is expected that as the particulates from the flue gas deposited on the collection plate of the ESP, their build up adversely affected the discharge current and reduced the collection efficiency. Frequent cleaning and maintenance of the collection plates and discharge electrodes were therefore required.

5. Conclusion

A small-scale and uncomplicated ESP for the removal of particulate matter from the exhaust gases of a small incinerator was developed and experimentally investigated. Its collection efficiency was analytically and experimentally evaluated. For particles larger than 10 μm, 100 % capture efficiency was predicted by the Deutsch-Anderson equation. It was shown that the efficiency decreased with decreasing in particle size. A prototype device was installed and operated successfully to a small-scale municipal incinerator of 1 ton per day. The collection efficiency of the ESP was evaluated as a mass loading ratio between the difference at the inlet and the outlet, to the particulate loading at the inlet of the ESP. The collection efficiency of this small-scale and uncomplicated electrostatic precipitator design was approximately 80 %.

6. Acknowledgement

This work was supported by the National Science and Technology Development Agency: Northern Network, Thailand, contract no. MT-RD-2553-02. We acknowledge Dr. Rainer Zawadzki's valuable contribution to the manuscript.

7. References

[1] White, H.J. (1963). *Industrial Electrostatic Precipitation*, Addison-Wesley, Reading, Massachusetts.

[2] Parker, K.R. (1997). *Applied Electrostatic Precipitation*, Blackie Academic & Professional, New York.

[3] Mizuno, A. (2000). Electrostatic Precipitation, *IEEE Transaction on Dielectrics and Electrical Insulation*, vol. 7(5), pp. 615 – 624.

[4] Jaworek, A., Krupa, A. and Czech, T. (2007). Modern Electrostatic Devices and Methods for Exhaust Gas Cleaning: A Brief Review, *Journal of Electrostatics*, vol. 65, pp. 133 – 155.

[5] Intra, P., Limueadphai, P. and Tippayawong, N. (2010). Particulate Emission Reduction from Biomass Burning in Small Combustion Systems with a Multiple Tubular Electrostatic Precipitator, *Particulate Science and Technology*, vol. 28, pp. 547 – 565.

[6] Ruttanachot, C., Tirawanichakul, Y. and Tekasakul, P. (2011). Application of Electrostatic Precipitator in Collection of Smoke Aerosol Particles from Wood Combustion, *Aerosol and Air Quality Research*, vol. 11, pp. 90 – 98.

[7] Hinds, W. C. (1999). *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*, John Wiley & Sons, New York.

[8] Elayyan, H.S.B., Bouziane, A. and Waters, R.T. (2002). Theoretical and Experimental Investigation of a Pulsed ESP, Journal of Electrostatics, vol. 56, pp. 219 – 234.