

CHAPTER 5
ENHANCEMENT OF ELECTROSTATIC PRECIPITATOR FOR
SUBMICRON PARTICLE COLLECTION BY NON-THERMAL PLASMA
PRE-CHARGER

In this chapter, a lab scale wire-cylinder electrostatic precipitator (ESP) with non-thermal plasma (NTP) pre-charger has been designed for study and evaluation. Enhanced NTP pre-charger was assembled in front of the wire-cylinder ESP under the pulse energization. The experiments were carried out effect of the enhanced NTP pre-charger on the collection efficiency of soot particle from diesel burner exhaust using the pulse-energized ESP under various dust loading and gas velocity. The collection efficiencies and energy consumption at different conditions were also considered.

5.1 Introduction

The recent day more countries are beginning to limit the emissions of micron and submicron particles. The process of collecting particles in ESP depends on the electric force acting on them. More the charge on the particle and high electric field, greater is the force on it. Therefore, it is important to increase the charge on submicron particle and electric field strength in order to enhance the collection efficiency of ESP. In our previous experiments, we demonstrated that the collection efficiency of pulsed-energized ESP was greater than that of the DC-energized ESP. In pulsed-energized ESP, the collection efficiency can be enhanced by increasing the pulse peak voltage but not more than break down limit. Another way to improve the collection efficiency of ESP by agglomerated submicron particle to large sized particle. The enhancement of charge on particle can be demonstrated by the increase in particle size, which is agglomerated by enhanced NTP pre-charger.

5.2 Experimental setup

The experimental setup is shown in Figure 5.1. The system mainly consists of an exhaust gas supply, two sections ESP, an aerosol system, and a particle concentration measurement system. The two sections ESP are in 1 m in length. The NTP pre-charger section consisted of two ground plate electrodes and a saw-tooth discharge electrode. The saw-tooth electrode (100 mm in length) and the plate electrodes (100 mm in width and 200 mm in length) were made of stainless steel. The saw-tooth electrode was placed midway between the ground plate electrodes. The ESP section was wire-cylinder configuration. A stainless steel pipe was used as a collection electrode. It had a 500 mm length with a 90 mm inside diameter. The discharge electrode was made of tungsten wire with 0.3 mm diameter and 500 mm effective length. The distance between discharge wire and collecting electrode was 45 mm.

A gas flow straightener was placed before the pulse corona plasma pre charger inlet. An exhaust gas of diesel combustion from a burner was introduced to the test unit at room temperature (35°C). The inlet concentration of the soot particles was adjusted at about 5×10^5 particles cm^{-3} and the velocity of the gas flow was controlled by a downstream blower with a speed controller.

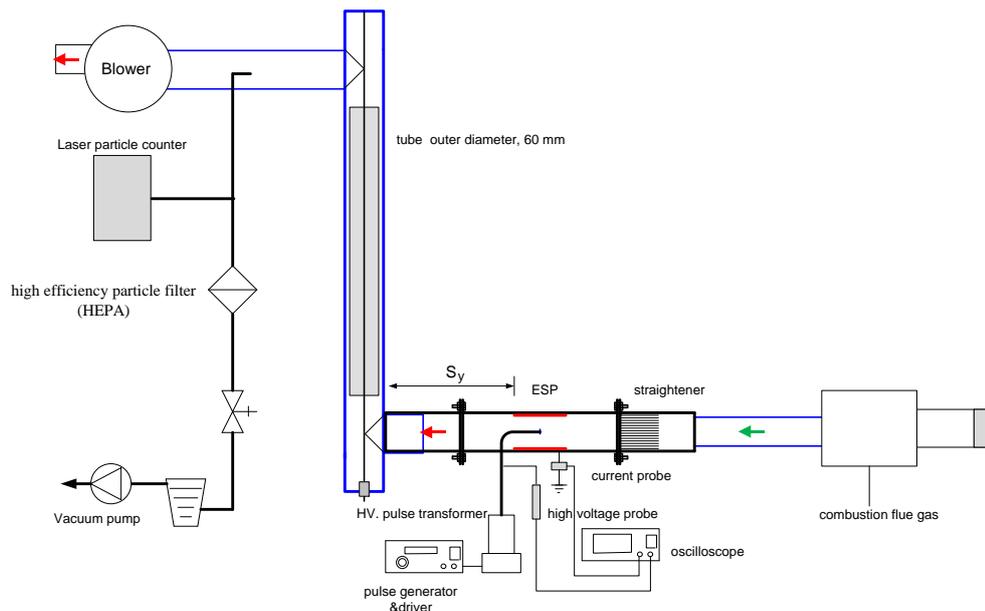


Figure 5.1 The experimental setup.

A high voltage pulse power supply with a function generator was used in this experiment. Pulse power supply can be adjustable pulse peak voltage from 0 to 45 kV. Waveform of the voltage was measured by an oscilloscope (Tektronix TDS 2014) and a high voltage probe (Tektronix P644A). Input power was measured with wattmeter connected to the low voltage side of step-up transformer. The overall collection efficiency of the ESP was evaluated with the mass loading of the particles measured at inlet and outlet of the two sections ESP.

$$\eta_t = 1 - \frac{M_{out}}{M_{in}}. \quad (5.1)$$

Where M_{in} is mass loading of particulate matter at the ESP upstream, and M_{out} is mass loading of particulate matter the ESP downstream. For each set of operating conditions, measurements were repeated a minimum of three times.

5.3 Results and discussion

5.3.1 Effect of the enhanced NTP pre-charger on collection efficiency of wire-cylinder ESP

Experiments were performed by setting the particle concentration at approximately 5×10^5 particles cm^{-3} . In NTP pre-charger, the supplied pulse peak voltage and pulse frequency were 45 kV and 20 Hz, respectively. Whereas, the wire-cylinder ESP was excited by 9 kV negative pulsed polarity. The gas flow velocity was adjusted from 0.5 ms^{-1} to 1.5 ms^{-1} in the wire-cylinder ESP section. Figure 5.2 shows the overall collection efficiency of the ESP as a function of gas flow velocity. Results are shown for both NTP pre-charger off and on mode. The results indicate that overall efficiency was greater than 90% for NTP pre-charger on mode tests, and greater than 70% for tests at NTP pre-charger off mode. Overall collection efficiency was substantially higher at NTP pre-charger on mode conditions than at NTP pre-charger off mode.

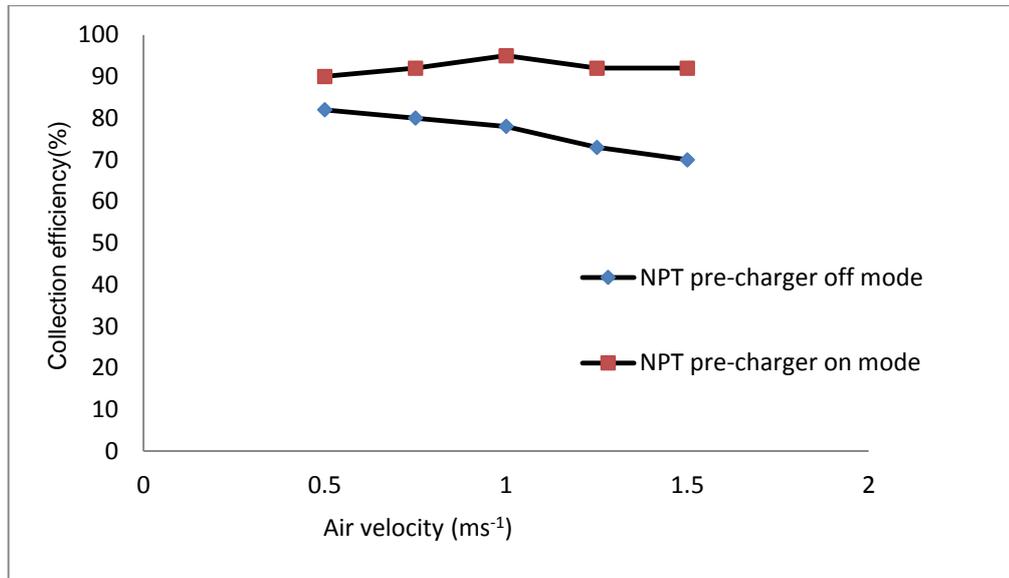


Figure 5.2 Variation of collection efficiency with air velocity at particle loading $>5 \times 10^5$ particles cm^{-3} , supplied voltages was 9 kV, when NTP pre-charger off and on mode.

5.3.2 Effect of supplied voltage on overall collection efficiency of the wire-cylinder ESP with NTP pre-charger

In the wire-cylinder ESP, gas flow velocity was controlled 1 ms^{-1} . Whereas, the pulse peak voltage was adjusted from 6 kV to 9 kV negative polarities. Figure 5.3 shows the overall collection efficiency of the ESP as a function of supplied voltage. Results are shown for both NTP pre-charger off and on mode. The results indicate that overall efficiency was greater than 95% for NTP pre-charger on mode tests, and greater than 75% for tests at NTP pre-charger off mode. Overall collection efficiency was substantially higher at NTP pre-charger on mode conditions than at NTP pre-charger off mode. Both curves appear to flatten and reach maximum values as the voltage was increased.

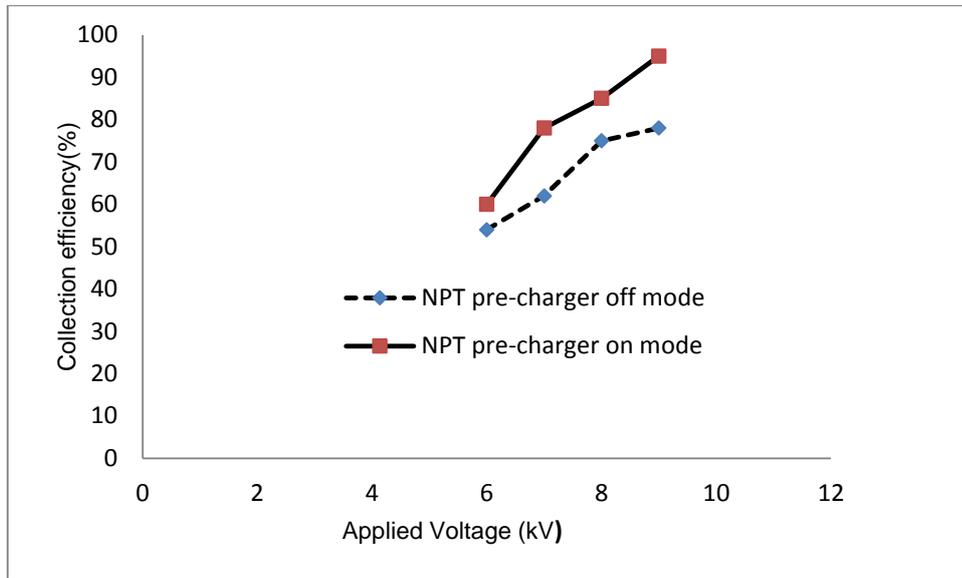


Figure 5.3 Variation of overall collection efficiency with supplied voltage at particle loading 5×10^5 particles cm^{-3} , gas flow velocity 1 ms^{-1} , when NTP pre-charger off and on mode.

5.3.3 Effect of the dust loading on overall collection efficiency of the wire-cylinder ESP with NTP pre-charger

The effect of the dust loading on overall collection efficiency was also investigated. Experiments were performed by setting the supplied pulse peak voltage and the pulse frequency to 45 kV and 20 Hz, respectively in the NTP pre-charger section. Whereas the wire-cylinder ESP was operated with 9 kV negative pulsed polarity. The gas flow velocity was adjusted from 0.5 ms^{-1} to 1.5 ms^{-1} in the wire-cylinder ESP section. Figure 5.4 shows the overall collection efficiency of the ESP as a function of gas flow velocity at the different dust loading. The mass concentration ranges were 20 mg m^{-3} , 45 mg m^{-3} and 100 mg m^{-3} , which were defined as low, middle and high dust loadings, respectively. A higher particle concentration led to high rate of particle collision at the high gas velocity, and thus the small particles could be easily agglomerated. As shown in Figure 5.4, the overall collection efficiency also increased with the increase of the dust loading and gas velocity.

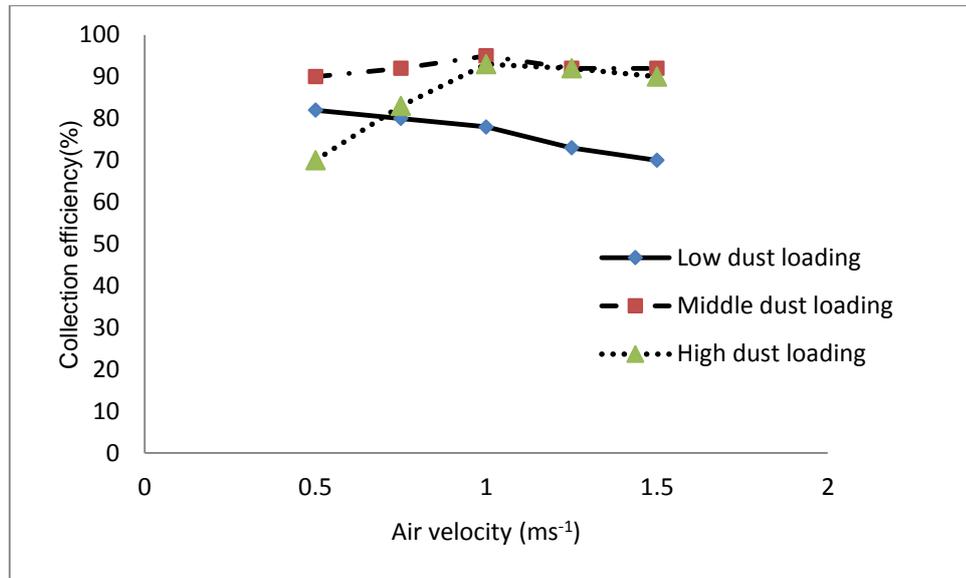


Figure 5.4 The overall collection efficiency with various gas velocity at difference dust loading and supplied voltages was 9 kV.

5.3.4 Modeling of the overall collection efficiency of the wire-cylinder ESP with NTP pre-charger

The wire-cylinder electrostatic precipitator (ESP) with non-thermal plasma (NTP) pre-charger has been designed for study and evaluation. The pulse energized NTP pre-charger was assembled in front of the wire-cylinder ESP. The experiments were carried out to find the effect of the enhanced NTP pre-charger on the collection efficiency of soot particle from exhaust gas of diesel burning. The overall collection efficiency of the whole system, η_c , is found to be correlate with the using different maximum voltages (V_{max}), frequencies (f_r), dust loadings (N) and gas flow velocities (U_g) Then

$$\eta_c = f(V_{max}, f_r, N, U_g). \quad (5.2)$$

The terms, V_{max} and f_r could be transformed into the average voltage, V_{ave} , as $V_{mean} = V_{mean} \times t_w \times f_r$ then the above relation could be rewritten as

$$\eta_c = f(V_{mean}, N, U_g, d). \quad (5.3)$$

A correlation could be set in a form of

$$\eta_c = cV_{mean}^{d1} \times N^{d2} \times U_g^{d3}. \quad (5.4)$$

From our experimental data, the correlation could be

$$\eta_c = 34.37 \times V_{mean}^{0.74514} \times N^{-0.021454} \times U_g^{0.094815}, \quad (5.5)$$

$$6 \text{ kV} < V_{max} < 10 \text{ kV},$$

$$1 \times 10^4 \frac{\text{particle}}{\text{cm}^3} < N < 5 \times 10^5 \frac{\text{particle}}{\text{cm}^3},$$

$$0.5 \text{ m/s} < U_g < 1.5 \text{ m/s}.$$

The results from the correlation could fit all the experimental data within 10 % deviation.

5.4. Conclusions

An NTP pre-charger has been used in wire-cylinder ESP to enhance the overall collection efficiency of soot particle. There are two advantages: (I) the submicron particle can be charged and agglomerated repeatedly. When the particles are agglomerated into a large particle, the charge on the agglomerated particles is increases when the particle is charged again. Thus the agglomeration rate goes up (II) because the particle can be bipolar charged in the NTP pre-charger and agglomerated at the same area. Therefore, the total length of the electric field becomes shorter in the application.

A model to predict the efficiency at various operating conditions could be evaluated from the experimental data as

$$\eta_c = 34.37 \times V_{mean}^{0.74514} \times N^{-0.021454} \times U_g^{0.094815}$$

$$6 \text{ kV} < V_{max} < 10 \text{ kV},$$

$$1 \times 10^4 \frac{\text{particle}}{\text{cm}^3} < N < 5 \times 10^5 \frac{\text{particle}}{\text{cm}^3},$$

$$0.5 \text{ m/s} < U_g < 1.5 \text{ m/s}.$$

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