4. RESULTS AND DISCUSSION

4.1 Collection Performance under Laboratory Experiment

In this work, a laboratory-scale wire-cylinder ESP was designed and built to investigate its collection performance. DC output voltage of the designed ESP was measured and shown in Fig. 17. As can be seen, the DC output signal is not actual DC voltage, it looks like a ripple signal. The peak of DC voltage signal was used for the calculation of theoretical collection efficiency of the designed ESP.

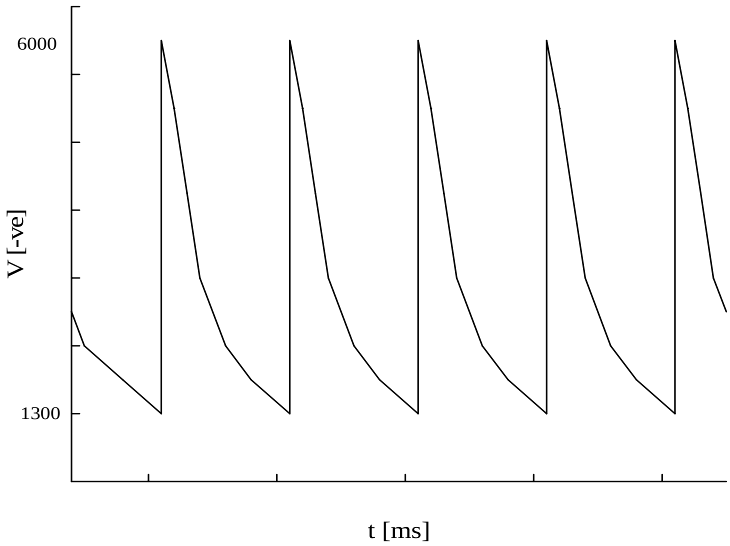

Figure 17. Characteristic of DC output signal.

Input-output voltage relation of the designed ESP is shown in Fig. 18. Result shows that the input-output voltage relation is linear. The maximum output voltage at the input of 220 V-rms (AC) is observed around 11 kV-peak (ripple). Discharge current-voltage characteristic was measured to determine the corona onset voltage of the designed ESP. A ripple direct current (DC) power supply was used to supply high negative voltage to discharge electrode. The current was measured between the collection electrode (cylinder wall) and ground. The relationship between output peak and discharge current is shown in Fig. 19. Results show that the corona onset voltage is around 8.0 kV-peak (ripple) of the supply voltage. The onset voltage region (8.0 kV-peak (ripple)), is corresponding to around 180 V-rms (AC) as shown in Fig. 18. As the supply voltage is lower than 8.0 kV-peak (ripple), the current is unnoticeably low. However, when the supply voltage is higher than 8.0 kV-peak (ripple), the current increases rapidly with the supply voltage. Moreover, when using the formula by White (1963) in Eq. (15), the initial voltage for 0.5 mm discharge electrode is calculated to be V_i = 10.9 kVDC.

$$V_i = aE_b \ln\left[\frac{R_{cy}}{a}\right] \tag{15}$$

where E_b is the breakdown potential, a and R_{cy} are the radius of wire and cylinder, respectively.

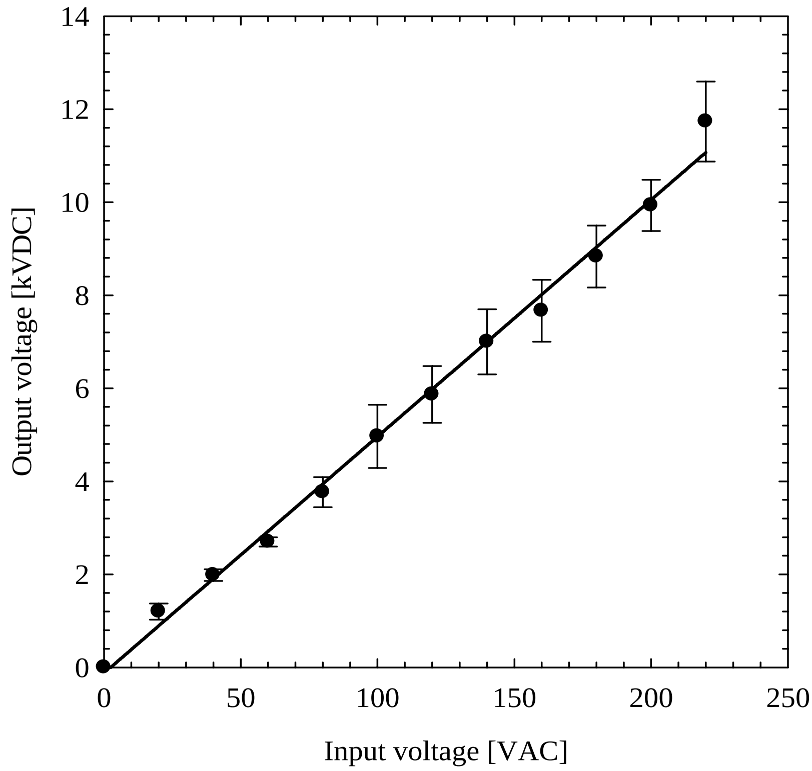

Figure 18. Input-output voltage relation.

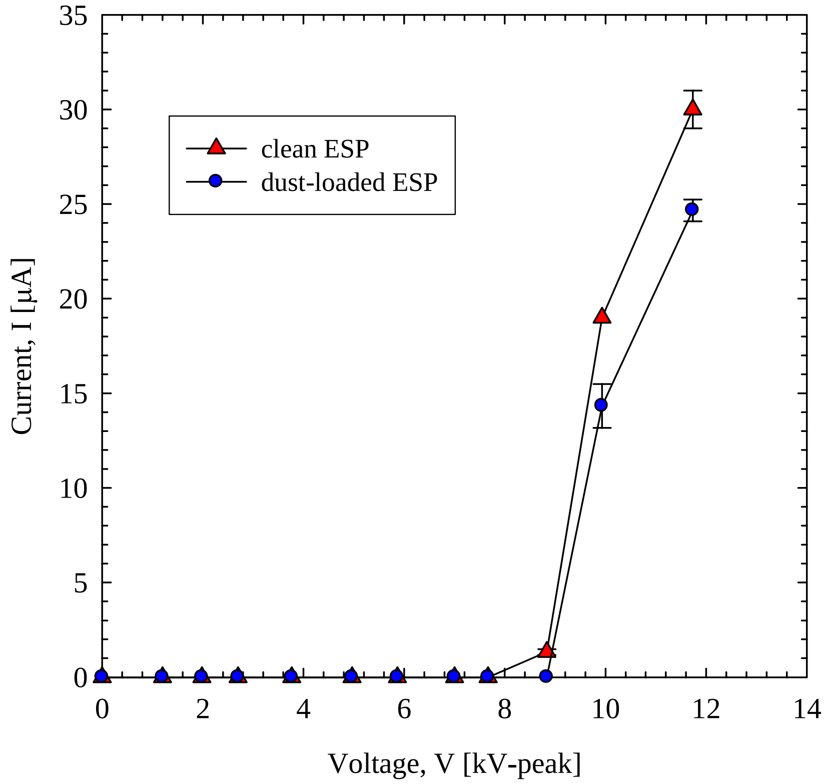

Figure 19. Current-voltage characteristic in the designed ESP.

4.1.1 Effect of applied voltage and velocity

The collection efficiencies for particle of 0.3, 0.5 and 1.0 micrometer as a function of velocity for different applied voltages are shown in Fig. 20, 20 and 22, respectively. Theoretical values calculated from Deutsch-Anderson equation are also shown for comparison purpose. However, when the supply voltage is below 180 V-rms (AC), the discharge current is very small and can not be measured accurately by the device so that the theoretical values are not calculated. From the results, it was found that when the applied voltage increases, the collection efficiency increases for all velocities and particle sizes. At highest supply voltage (220 V-rms (AC)) the collection efficiency is maximum since the applied voltage is proportional to the electric field strength inside the ESP and, at high electric field strength, the particles deposit on the collecting surface immediately. However, when the applied voltage is lower than 180 V-rms (AC) or 8.0 kV-peak (ripple), the collection efficiency is low for all velocities and particle sizes, since the onset of corona discharge occurs at about this voltage as shown in Fig. 19. The theoretical values are in agreement with experimental results, especially for 1.0-micrometer particle size both at 180 and 220 V-rms (AC) supply voltages. At 180 V-rms (AC) supply voltage, for 0.3 and 0.5 micrometer particle sizes, the maximum difference between theoretical values and experimental results is about 30 % since the onset of corona discharge just occurs in this voltage and ion adsorption ability of smaller particles is less than when compared with larger particles. However, at 220 V-rms (AC) supply voltage, the collection efficiency of 0.3 micrometer particle size is higher than theoretical values for most velocities. The maximum difference in collection efficiency is found to be 20 %. This may be from the variation of supply voltage which was applied to the ESP during experiment. Moreover, the results also indicate that the collection efficiency decreases when the velocity increases for all particle sizes. At the higher velocity, the particles do not have sufficient time to reach the collection surface or, in other word, the residence time of the particles is reduced.

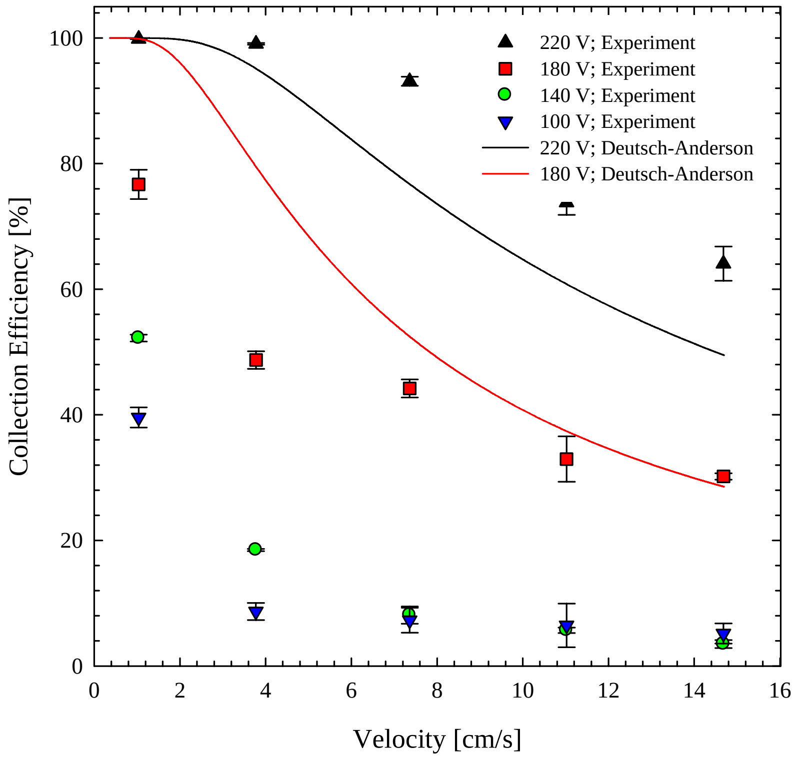

Figure 20. Effect of applied voltage on the collection efficiency for 0.3-µm particles.

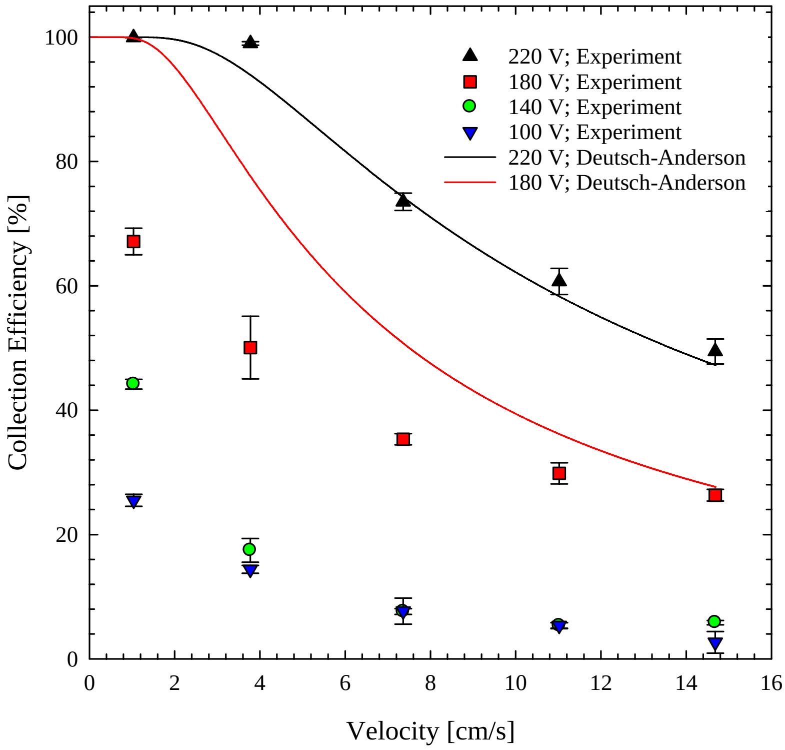

Figure 21. Effect of applied voltage on the collection efficiency for 0.5-µm particles.

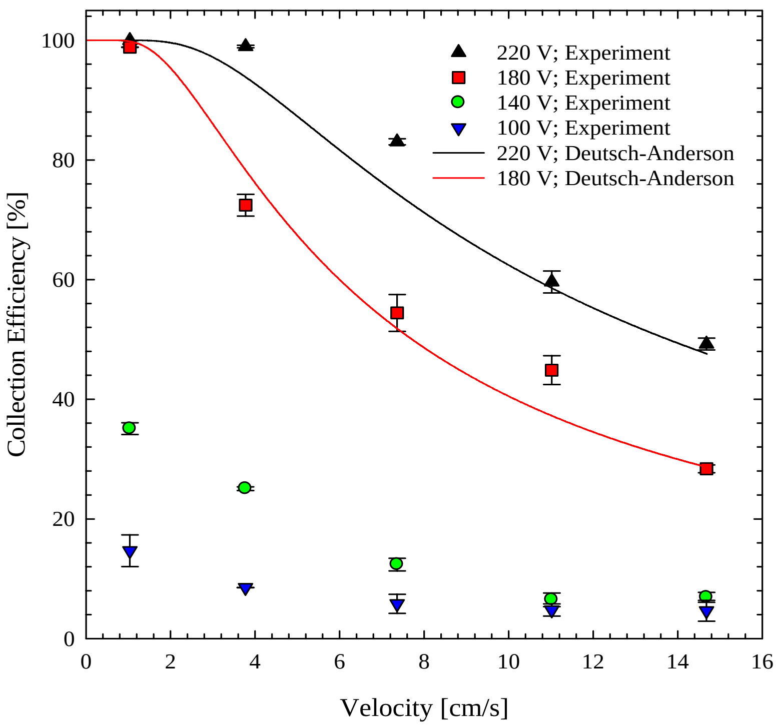

Figure 22. Effect of applied voltage on the collection efficiency for 1.0-µm particles.

4.1.2 Effect of particle size

4.1.2.1 Low electric field strength

Particle size is found to play an important role in relatively low electric field region because at high electric field region particles can be deposited on the collection surface readily regardless of the Brownain motion of small particles. Fig. 23 to 25, show the effect of particle size on the collection efficiency in low electric field regions, supply voltage of 100 and 140 V-rms (AC) for 3 different velocities. The results indicate that small particle shows better collection efficiency than large particle for most of the velocities. It can be seen that the collection efficiency of 0.3 micrometer particle sizes is 10 % and 20 % higher than that of 1.0 micrometer particle size, respectively for the supply voltage of 140 and 100 V-rms (AC), at the lowest velocity of 1.04 cm/s. For 0.5-micrometer particles, the collection efficiency is about 10 % higher than that of 1.0 micrometer particles. This is due to the influence of Brownain motion of small particles and diffusion charging mechanism which is the dominant mechanism in the low electric field strength. However, at the high velocity, 7.36 and 14.68 cm/s, the collection efficiency is very low for all particle sizes because the electric field strength inside the ESP is very weak so that it is not enough to generate corona discharge to give charge to particles. The maximum collection efficiency is about 13 % at the velocity of 7.36 cm/s for 140 V-rms (AC) of supply voltage.

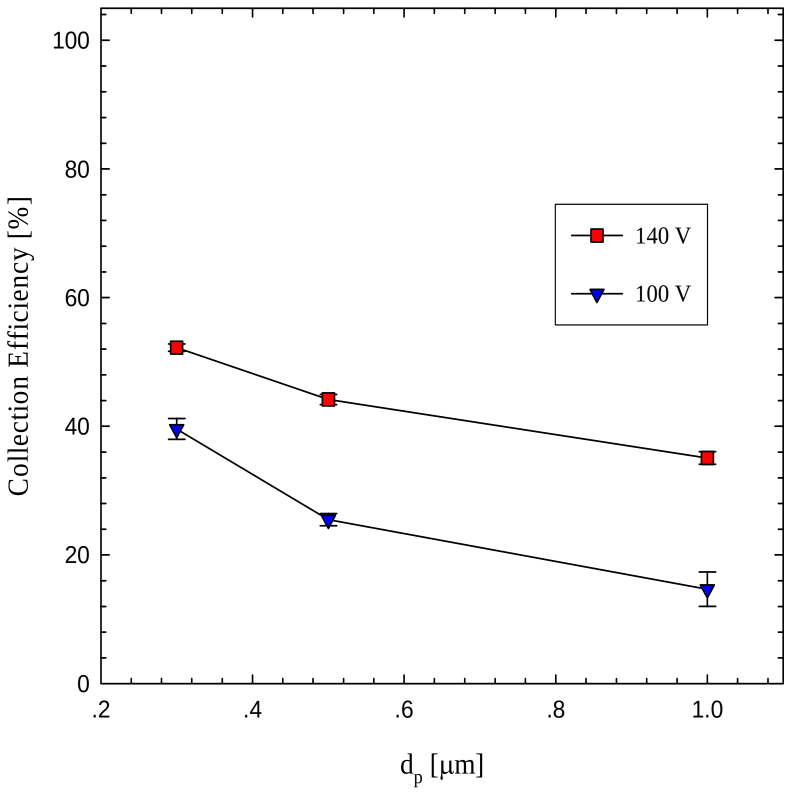

Figure 23. The effect of particle size on the collection efficiency at 1.04 cm/s.

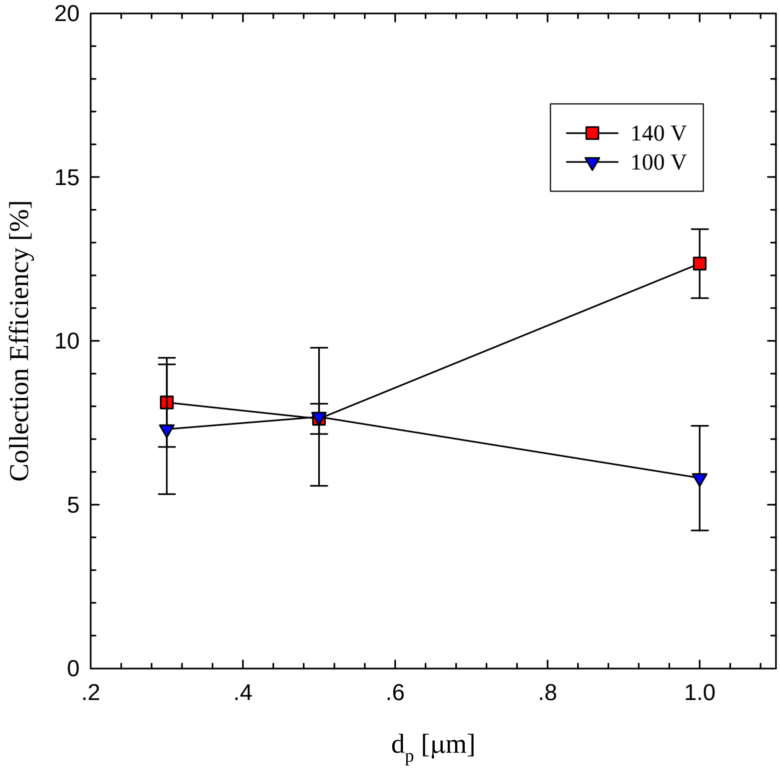

Figure 24. The effect of particle size on the collection efficiency at 7.36 cm/s.

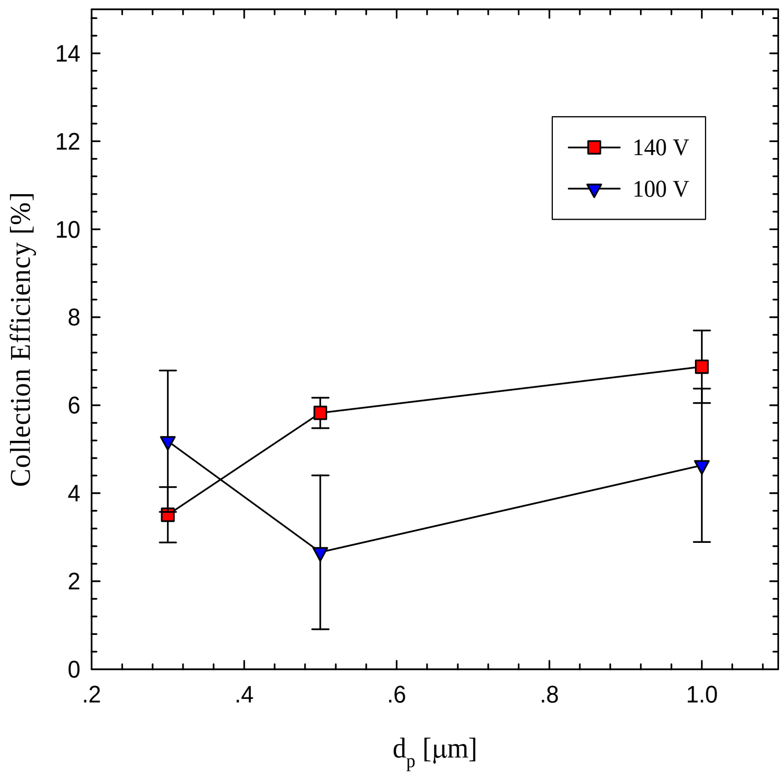

Figure 25. The effect of particle size on the collection efficiency at 14.68 cm/s.

4.1.2.2 High electric field strength

The effect of particle size on the collection efficiency at high electric field region is shown in Fig. 26 to 28. Results show that the collection efficiency increases with increasing the supply voltage. At the maximum voltage (220 V-rms (AC)) the collection efficiency is highest for all particle sizes and velocities. Moreover, the collection efficiency is nearly independent of particle size. This may, due to enough electric filed strength to generate corona discharge to give charge to all particles in the gas stream. Therefore charged particles can be deposited on the collection surface immediately when they flow into the electric field. At the supply voltage of 180 V-rms (AC) where the onset of corona discharge just occurs, the particle size of 1.0 micrometer shows 20 % and 30 % higher collection efficiency than that of 0.3 and 0.5 micrometer, at the lowest velocity of 1.04 cm/s. This is due to ion adsorption ability of large particles. The ions can be more easily adsorbed on large particles. Therefore, the electric forces are much stronger on large particles and it can reach the collection surface rapidly when compared with smaller particles. However, at the highest velocity of 14.68 cm/s, the difference in collection efficiency is not significant for all particle sizes. The collection efficiencies are about 55 % and 30 % at the supply voltage of 220 and 180 V-rms (AC), respectively.

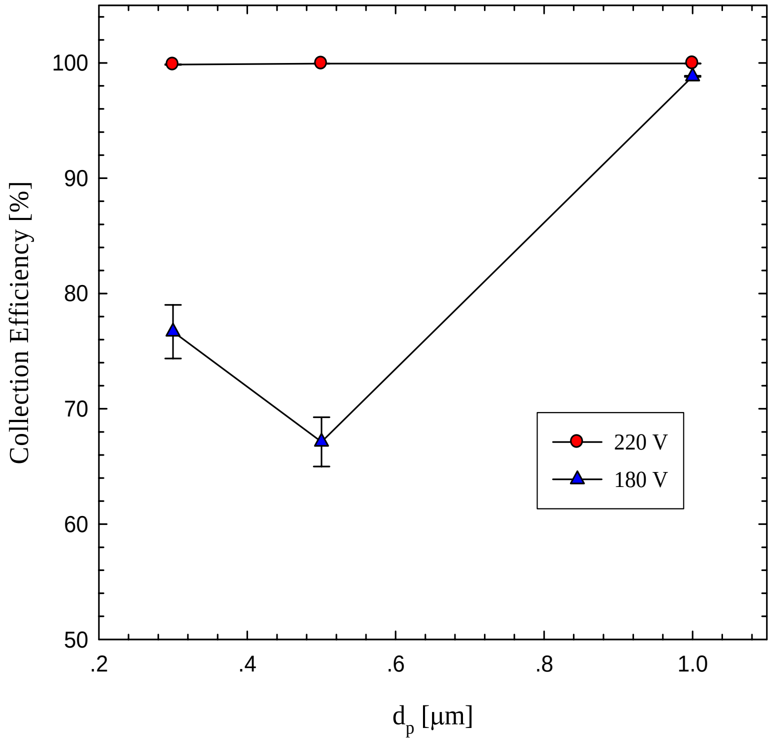

Figure 26. The effect of particle size on the collection efficiency at 1.04 cm/s.

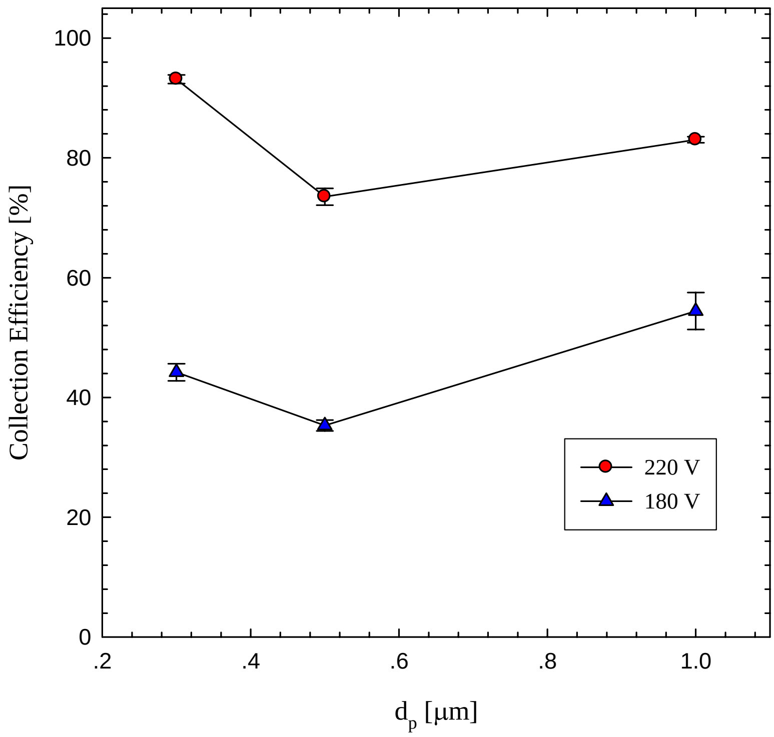

Figure 27. The effect of particle size on the collection efficiency at 7.36 cm/s.

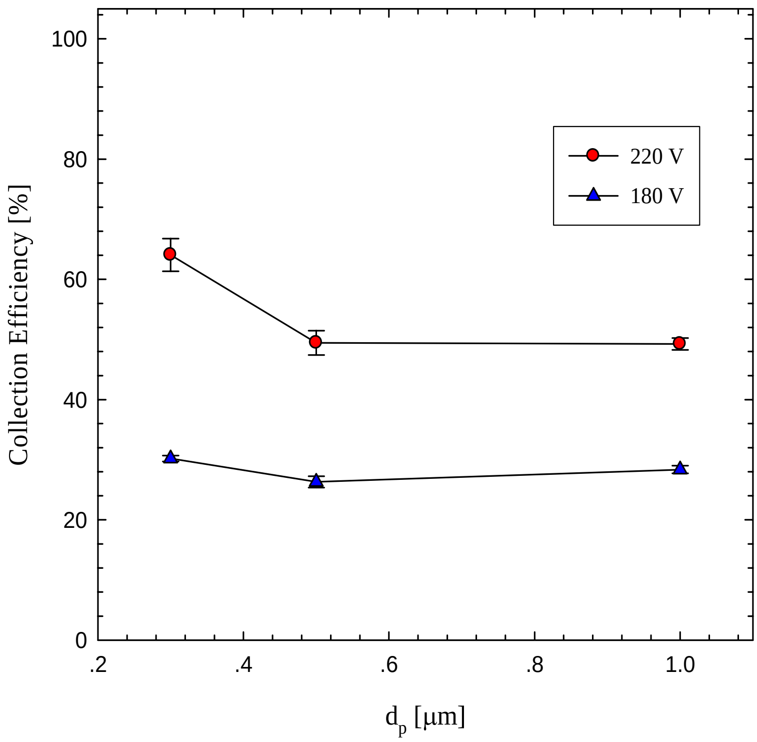

Figure 28. The effect of particle size on the collection efficiency at 14.68 cm/s.

4.1.2.3 Pressure drop

Pressure drop is a parameter which used to determine the collection performance of the designed ESP. The pressure drop is the resistance of the air which flow through the ESP. In the experiment, pressure drop is measured across upstream and downstream of the ESP. The measured data is summarized in Table 5 and shown in Fig. 29.

Table 5. The experimental results for measuring the pressure drop of the ESP.

Velocity, *U* (cm/s)	Pressure drop, *ΔP* (torr)			Average	SD
	1	2	3		
1.04	0.02	0.03	0.03	0.03	0.01
3.77	0.02	0.03	0.03	0.03	0.01
7.36	0.02	0.03	0.03	0.03	0.01
11.02	0.03	0.03	0.04	0.03	0.01
14.68	0.03	0.03	0.04	0.03	0.01

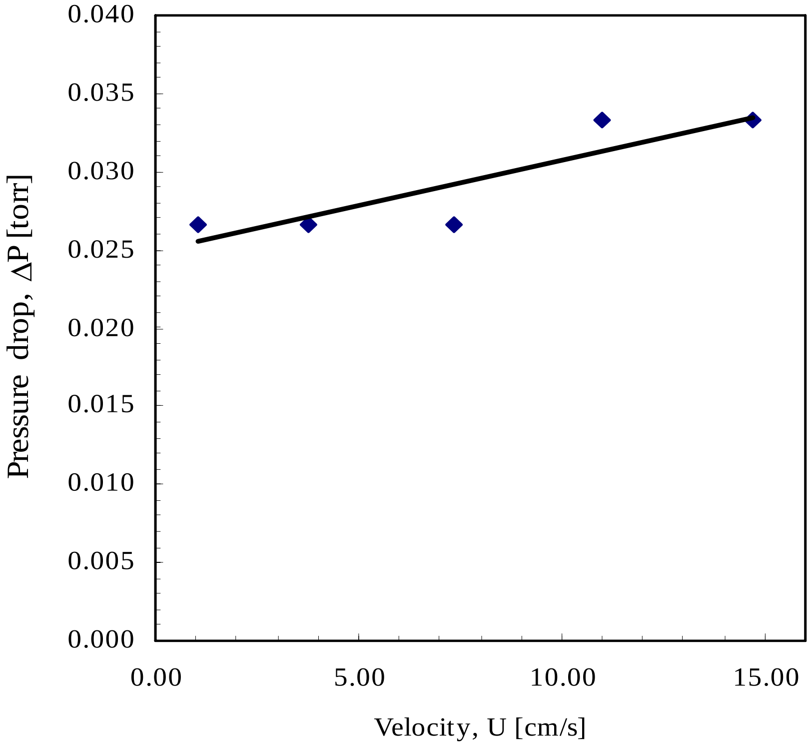

Figure 29. Measured pressure drop as a function of velocity.

Results show that the pressure drop of the ESP slightly increases with increasing the velocity due to pressure drop is proportional to velocity. However, the pressure drop is very low for all velocities. The pressure drop is about 0.03 torr for most velocities.

4.2 Collection Efficiency under Working Condition

Dust-loading plays an important role in ESP performance. In general, when the ESP is operated under high dust-loading condition, its collection efficiency is relatively low, especially for submicron and ultrafine particles (Chang, et al., 1998). Fig. 30 shows the relationship between the loading of dust or collected particles on the ESP and operation time. From the figure, it can be observed that the loading of dust on the ESP increases almost linearly as the operation time increases because the amount of dust flow to the ESP increases when the operation time increases.

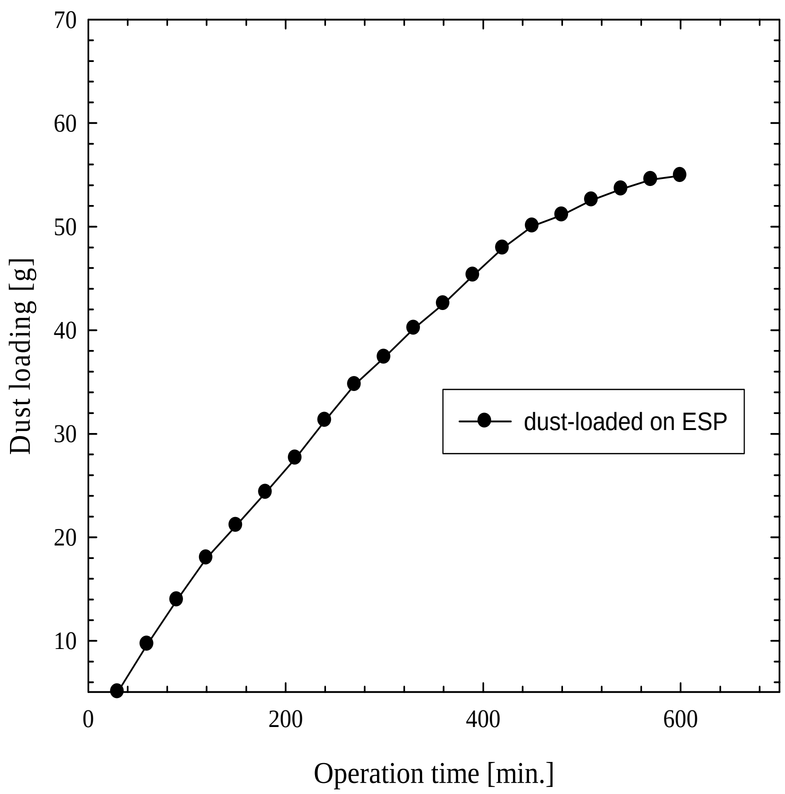

Figure 30. The relationship between the loading of dust and operation times.

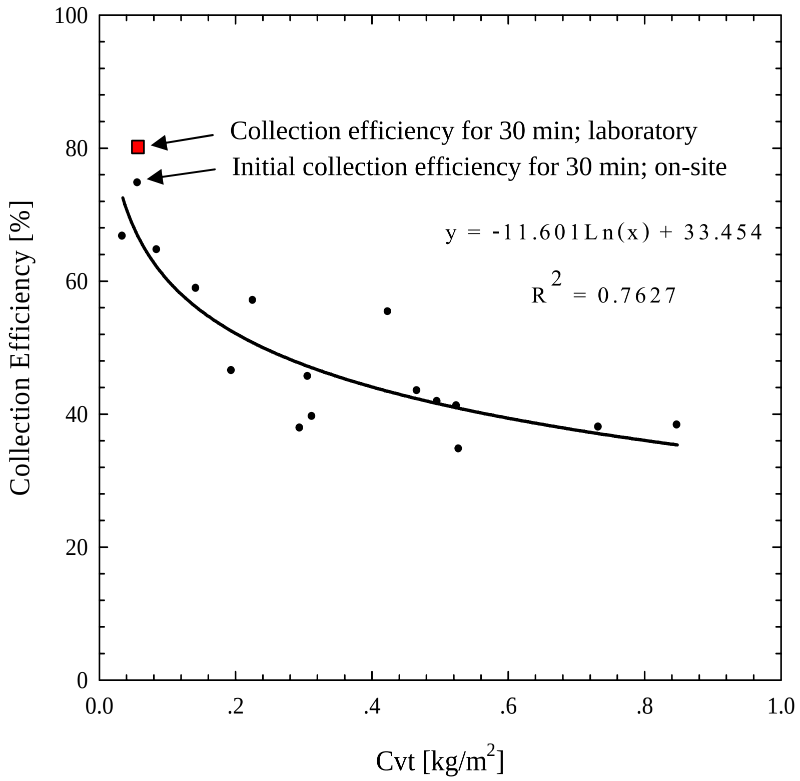

Figure 31. The influence of dust-loading on the collection efficiency on site. test.

Fig. 31 shows the influence of dust-loading on the collection efficiency of the designed ESP during on site test. It is found that as particle concentration and operation time increase, the collection efficiency of the ESP decreases. This is in agreement with Chang's experiments. The loading of dust on the electrode reduces the electrical interactions between collecting surface and charged particles. This can be seen from the discharge current that decreases after 10 hours operation as shown in Fig. 19. Moreover, the re-entrainments of particles from collection electrode when operation time increases may be responsible for the collection efficiency reduction. Fig. 32 shows the influence of dust-loading on the collection efficiency in laboratory. The result is obtained by installing the clean ESP into the rubberwood burner for 30 minutes at the flow rate of 20 L/min of rubberwood combustion. After that, the collection efficiency of the dust-loaded ESP is measured and tested in laboratory to study the effect of dust loading on the designed ESP at various velocities. The collection efficiency at 20 L/min or 7.36 cm/s of velocity in laboratory is used for comparison with the collection efficiency of the on-site test. It can be seen that the initial collection efficiency under dust-loading condition for 30 minutes of the on-site test is slightly less than experimental result in the laboratory. The collection efficiencies are found to be around 75 % for on site test and 80 % in laboratory, respectively. Note that it is different in the calculation of collection efficiency which one based on mass concentration [kg/m^3] at the on-site test and the other based on number concentration [#/L] in the laboratory, respectively.

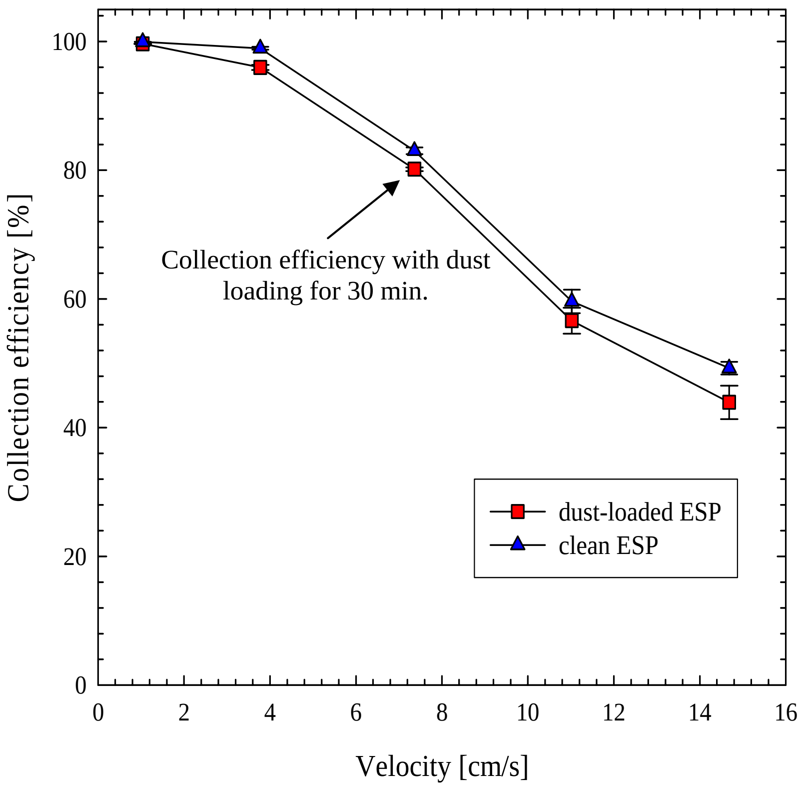

Figure 32. The influence of dust-loading on the collection efficiency in laboratory.

The designed ESP under laboratory conditions gives high aerosol collection efficiency. It is effective to remove the soot particles or particulate in the atmosphere. The collection efficiency of the designed ESP increases with increasing the supply voltage, however, its collection efficiency decreases when the velocity increases. At the same supply voltage, the collection efficiency decreases when the velocity increases since the residence time of particles is reduced. Particle size plays an important role in relatively low electric field strength. Small particles show higher collection efficiency than large particles due to the influence of the Brownain motion and diffusion charging mechanism of small particles. At high electric field strength, the collection efficiency is independent of particle size. Furthermore, dust-loading effect also plays an important role in the ESP performance. The loading of dust on the ESP increases and its collection efficiency decreases as the operation time increases since the electrodes are contaminated with particulate and collecting surface is then reduced.