EVALUATION OF ELECTROSTATIC PRECIPITATOR PERFORMANCE FOR SUBMICRON PARTICLE SIZE RANGE

V. Agranovski, L. Morawska, Z. Ristovski, M. Jamriska

Centre for Medical and Health Physics, Queensland University of Technology, Australia

ABSTRACT

The fractional collection efficiency (FCE) tests of a commercially available two-stage electrostatic precipitator (ESP) have been performed for six flow rates. The tests covered the particle size range from 0.018-1.2μm using two types of test aerosols, NaCl and environmental tobacco smoke (ETS). Measurements were performed by means of two Scanning Mobility Particle Sizers (SMPS) and the Aerodynamic Particle Sizer (APS). For the cases evaluated, the total collection efficiency (TCE) of the precipitator was found to increase with the increase of count median diameter of the particulate, to have no significant dependence on the type of test aerosol, and has been demonstrated to have a polynomial dependence on flow rate. The collection efficiency was found to be independent of particle size at flow rates below 560 L/s. At higher flow rates, however, a significant dependency of the collection efficiency on the particle size was observed. A minimum in the efficiency was detected in the range from 0.1 to 0.45μm and for particles smaller than about 0.02μm.

KEYWORDS: aerosol, air cleaning, ESP, particle size distribution, performance

INTRODUCTION

The increasing demands on control of fine particulate emissions have resulted in increasing requirements for improved control devices' performance in this particle range. The electrostatic collection of aerosol particles is one of the most widely used air cleaning methods. The ESPs have been utilised to clean air in industrial ventilation applications and in smaller scale devices used for enhancing indoor air quality in offices, homes and public buildings such as clubs, schools, shops, etc. In general, an ESP performance depends on electrical and mechanical design and the characteristics of both gas media and aerosol particles [1]. The removal efficiency of an ESP is reported to be highly particle size dependent [2]. The work presented in this paper is a continuation of work [3]. The aim of this study was to assess the ESP efficiency for removing ETS under controlled laboratory conditions and to evaluate the collection efficiency of the ESP as a function of particle size (focusing on submicrometer particulate) over a range of face velocities.

METHOD

The experimental set-up consisted of a duct system, a system for supplying HEPA filtered air, an ESP, an aerosol generation system, an aerosol sampling and transport system, and a particle size distribution monitoring system.

The commercially available two-stage IONITRON electrostatic precipitator supplied by Email Airhandling was tested in the present work. The characteristics of the precipitator are given in Table 1.

Table 1. Operating parameters of the IONITRON electrostatic precipitator.

Parameter	Symbol	Units	Value
Width of charging cell	W_1	mm	110.0
Length of charging cell	L_1	mm	535.0
Radius of wire	R_w	mm	0.075
Width of collecting cell	W_2	mm	301.5
Length of collecting cell	L_2	mm	562.0
Voltage of corona wire	V_1	kV	13.0
Voltage of plate	V_2	kV	6.5
Number of plates	N_p	-	61
Distance between plates	D_p	mm	7.0

Test rig

The tests were performed at a filter test rig designed according to the AS 1324.2 - 1996 standard, which is based on the ASHRAE Standard 52.1 – 1992. The system allows testing of filters under three modes: draw-through, blow-through, and recirculating. In this study the filters were tested under the draw-through (negative pressure) mode. The upstream and downstream aerosol was sampled isokinetically using two identical probes of the same length.

Particle measurement instruments

The APS and two SMPSs were used to measure particle size distributions and concentrations. The SMPSs were calibrated against each other in order to measure downstream and upstream concentration concurrently. Summary of the particle instruments is given in Table 2.

Table 2. Specification of particle instruments

Instrument	Particle Detection Method	Size Range, μm	Concentration Range, particle/cm^3	Display Resolution, channels per decade	Sampling Time, s
SMPS-3934 (TSI)	CPC-3025A (TSI)	0.005-1	20-10^7	4, 8, 16, 32 or 64	60-600
SMPS-3934 (TSI)	CPC-3010 (TSI)	0.01-1	1-10^7	4, 8, 16, 32 or 64	60-600
APS-3320 (TSI)	Spectrometer	0.5-20	1-10^3	32	1-64800

Testing aerosols

Two types of test aerosols were used to evaluate the removal efficiency of the precipitator in the submicrometer range: NaCl and ETS. The ETS was an aerosol of particular interest under the present project. It was generated by the ETS generator designed at the Environmental

Aerosol Laboratory of the QUT and manufactured by Email Airhandling for the purpose of these studies. It allows simultaneous smouldering of up to twenty cigarettes.

The NaCl aerosol was selected as the alternative challenge aerosol for the tests. It was assumed that the results obtained by using NaCl aerosol will give reasonable information about the properties of the precipitator when exposed to various test aerosols, including ETS. The polydisperse NaCl test aerosol was generated by nebulising 10 and 20% aqueous NaCl solutions using a Collison nebuliser. Following generation, the aerosol was passed through a charge neutraliser (TSI Model 3012) to eliminate any electrostatic charge on the particles and thus to avoid uncontrolled electrical effects.

Test procedure

The tests were performed under the draw-through mode at volumetric flow rates of 472, 560, 708, 800, 944, 1024, and 1050 L/s. The particle measurements were made over the size ranges of 0.18 – 0.7 μm using the SMPS and of 0.5-1.2μm using the APS. For each set of conditions, a series of three upstream and downstream background concentrations were measured. The aerosol generator was then turned on, allowed to stabilise for 5-10 minutes, and another series of upstream and downstream measurements were performed without the precipitator in the system (P_{100}, 100% penetration tests). The purpose of the P_{100} tests was to evaluate the adequacy of the overall duct, sampling, and measurement systems. After the P_{100} measurements were obtained, the precipitator was activated and particle size fractional efficiency tests were carried out. The measurement procedure included three sequential measurement pairs of upstream and downstream sample concentrations to obtain the challenge and penetrating aerosol concentrations, respectively. The average of these results was used to calculate the removal efficiency. In the case of the ETS aerosol, a concurrent sampling regime of upstream and downstream concentrations was selected in order to minimise the effect of the ETS generator variability. Each measurement was taken over a time period of two minutes. The *penetration,* P, corresponding to the different particle size channels of the particle size analyser was calculated as:

$$P = P_{100} \frac{D_{avr} - D_{bkg}}{U_{avr} - U_{bkg}} \qquad \text{.... (1)}$$

where D_{avr}, U_{avr}, D_{bkg}, and U_{bkg} are averaged downstream and upstream challenge aerosol and background concentrations and P_{100} is a coefficient derived from "100% penetration" tests. The corresponding removal *efficiency,* Eff, was calculated as:

$$\text{Eff} = (1 - \text{P}) \times 100\% \qquad \text{....(2)}$$

RESULTS AND DISCUSSION

Tests with the NaCl challenge aerosol

Fig.1 and Fig.2 represent the size distribution of upstream and downstream NaCl aerosol (generated from the 10% solution) at two extreme flow rate values of 1050 and 472L/s, respectively. The spectra were unimodal with a count median diameter (CMD) of about 0.17μm with the geometric standard deviations (GSD) typically within 1.5 –1.7. The spectra of the aerosol generated from the 20% solution were similar to those in Figs 1 and 2 and had a CMD of about 0.7 µm (with GSP of 1.6-1.8).

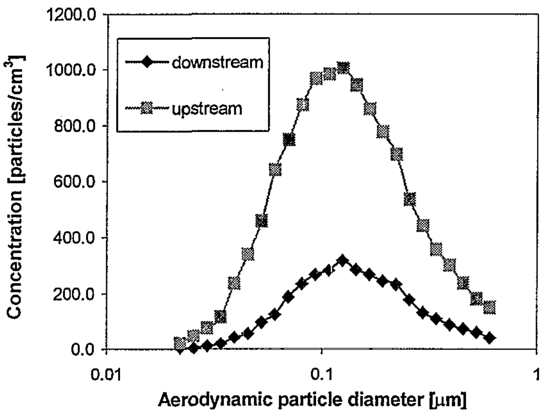

Fig.1 NaCl aerosol spectra at 1050 L/s

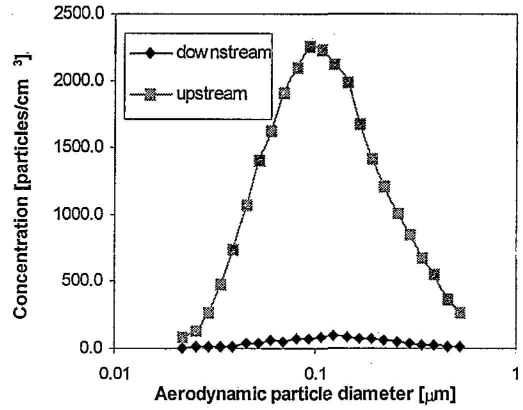

Fig.2 NaCl aerosol spectra at 472 L/s

The results of the fractional collection efficiency tests over the range of about 0.2 –1.2µm are summarised in Fig.3. As can be seen, the collection efficiency of the precipitator increases with a decrease in the flow rate. It is also demonstrated that efficiency is significantly dependent on the particle size. However, this dependence reduces with a decrease of the flow rate to such an extent that the collection efficiency becomes fully independent of the particle size. For example, at flow rates below 560 L/s, the efficiency was found to be almost independent of the particle size, within the limits of the experimental error (about 5%). At flow rates above 560 L/s, the results show that increasing the particle size leads to: (1) an increase in the removal efficiency of small particles, up to about 0.025-0.035µm [1]; (2) a decrease in the removal efficiency of the larger particles over the range from about 0.025-0.035µm to about 0.080-0.1µm [1]; (3) an independence of the collection efficiency on the particles size for the particles over the range from about 0.08-0.1µm to about 0.45µm [1]; (4) an increase in the collection efficiency for particles larger than about 0.45-0.5µm.

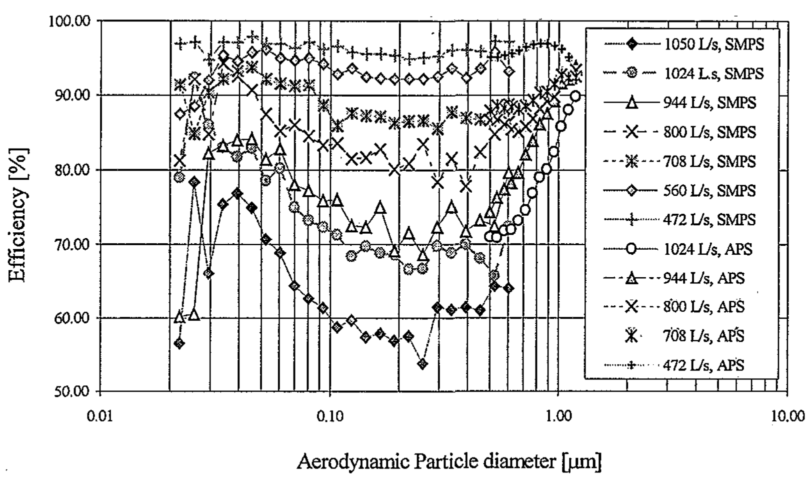

Fig.3 Dependence of fractional filtration efficiency on air flow rate for the NaCl aerosol

[1] This range seems to depend on the flow rate

In summarising the results of tests performed at the flow rates greater than 560 L/s, the following trends can be seen: (1) the highest collection efficiency is achieved over the range from about 0.025 to 0.04μm; (2) the lowest collection efficiency is achieved for particles smaller than about 0.02μm and over the range from about 0.1 to 0.45μm.

These results can be explained by the collection mechanism and operation principle of the electrostatic precipitators. The lower efficiency of extremely small particles (less than 0.02μm) can be attributed to the charging limitations of the particles, and the lower efficiency of larger particles can be attributed to their mobility limitations. An increase in the diameter of a charged particle corresponds to a decrease in its electrical mobility. Thus particles with larger diameters will travel shorter distances over the same time period than smaller diameter particles, when under the influence of an electric field. For a high flow rate through an electrostatic precipitator, some larger particles may not have enough time (due to their small electrical mobility) to traverse the field and deposit onto the precipitator plates. In this case, the collection efficiency of the precipitator for this particle size is very low. There is no sharp cut-off point for the efficiency however, as all particles do not carry the same charge, and they do not enter the precipitator at the same distance from the plates. Particles with a higher charge can have the same mobility as smaller particles with a lower charge, and can thus be collected. Particles entering close to the precipitator plates will require less time to be collected than particles entering mid-way between the plates.

The results of the total collection efficiency tests are presented in Fig.4 where the effect of the flow rate on the total collection efficiency for the two cases investigated (test with the NaCl aerosol with CMD of 0.17 and 0.7μm) is demonstrated. Two trends were observed: (1) the total collection efficiency is increased with the increase of particle size. For example, at a flow rate of 944 L/s, the total collection efficiency values of 75.19% and 80.39% were found to correspond to the aerosols with CMD of 0.17 and 0.7μm, respectively; (2) there is a polynomial dependency of the total collection efficiency on the flow rate.

Tests with the ETS challenge aerosol

The tests were carried out under the draw-through mode with volumetric flow rates of 472 and 944 L/s. The effect of the flow rate on the fractional collection efficiency observed is shown in Fig.5.

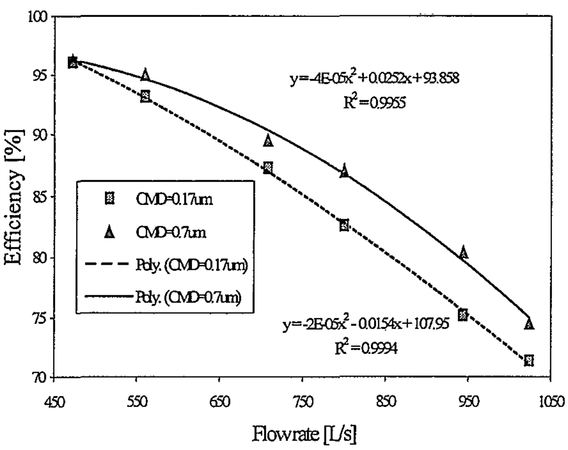

Fig. 4 Total efficiency for the NaCl aerosol

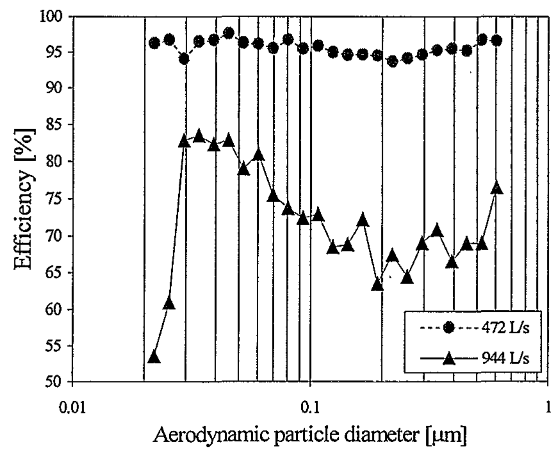

Fig.5 Fractional efficiency data for ETS

The results indicate that efficiency decreases with the increase of the flow rate in much the same way as happens in the case of the NaCl aerosol. Total collection efficiency values of 71.8 and 95.2 % were found for flow rates of 944 and 472 L/s, respectively.

CONCLUSIONS

1. For the cases evaluated, the TCE of the ESP appears to have no significant dependence on the type of test aerosol, but does depend on particle size. The TCE values of 95.2 ± 10 % and 96.1 ± 5 % were found to correspond to the rated flow rate of 944 L/s for the ETS and the NaCl (CMD=0.17μm) test aerosols, respectively.
2. The total efficiency was found to increase with the increase of particle size.
3. There is a polynomial dependency of the TCE on the flow rate.
4. The FCE was found to be dependent on flow rate. However, the "critical" particle size of about 1.2μm was found to exist when the collection efficiency appears to be independent of flow rate.
5. The collection efficiency appears to be independent of particle size at flow rates below 560 L/s. At higher flow rates, however, a significant dependency of the efficiency on the particle size was observed. A minimum was found in the range from 0.1 to 0.45 μm and for particles smaller than about 0.02 μm. The lower collection efficiency of extremely small particles is attributed to the charging limitations, and that of larger particles to their mobility limitations.

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REFERENCES

1. Durga-Prasad, NVPR et al, 1995. Automatic control and management of electrostatic precipitator, *IEEE/IAS International Conference on Industrial Automation and Control* (IAS'95), pp.389-94.

2. Hanley, J.T., Ensor, D.S., Smith, D.D., Sparks, L.E., 1994. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners, *Indoor Air*, v 4, pp. 169-178.

3. Jamriska, M., Morawska, L., Ristovski, Z., 1998. Performance assessment of electrostatic filters with a focus on submicrometer particles, *J. Aerosol Sci.,* Suppl.1, pp. S1129-1130.