

Dust anchoring characteristics of electret fibres with respect to Der p 1 allergen carrying particles

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Abstract—The avoidance of house dust mite allergens is a major area of interest and essentially requires a significant removal of these allergens from the immediately respirable air. Electrostatic attraction and anchoring of particulate matter using electret polymers is commonly used for air filtration purposes. This effect is investigated for its possible use in domestic allergen avoidance. Polypropylene electret, heat-treated electret and non-electret, and wool and nylon fibre samples were soiled with house dust known to contain Der p 1 allergen. These samples were vacuumed at three air face velocities. The proportions of released and anchored dust were calculated. Released dust was collected and analysed for Der p 1 concentration and compared to stock dust values. Results showed that compared to uncharged fibres at least 95% more dust remained anchored in the electret fibres. Also, overall Der p 1 release was reduced by more than 49%. Der p 1 allergen concentrations in the collected dust were relatively constant for all the fibres tested, indicating no selective attraction or repulsion of Der p 1 allergen carrying particles in the experimental dust. The consistently high dust anchoring ability of the electret fibres could be used in many domestic products that are known to harbour particulate allergens, to reduce their release and inhalation.

Keywords—House dust mite, Allergen avoidance, Electrostatic anchoring, Der p 1, Particle size

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1 Introduction

CONTROL OF house dust mites (HDM) and their allergens in the domestic environment has been a major area of interest for the past few decades owing to their link in initiating and aggravating atopic diseases such as allergic asthma. Many chemical and physical methods of control have been investigated as a result, with varying degrees of efficacy (reviewed in: COLLOFF *et al.*, 1992; FEATHER *et al.*, 1993; PLATTS-MILLS *et al.*, 1992; TOVEY, 1992; PLATTS-MILLS and CHAPMAN, 1987). All methods appear to be inherently transient in their effect and require a continued treatment programme to maintain control levels.

One form of physical control that has not yet been specifically studied is restriction of respirable HDM allergen to the areas in which it is found, by means of electrostatic particulate adhesion. By anchoring dust particles to specific surfaces, it may be possible to reduce the amount of airborne allergen and make targeting of other control methods easier and more effective.

Materials exist that contain trapped electric charge that does not change with most environmental or physical conditions. These materials are known as electrets. Electret polymer fibres are used extensively for gas particle filtration purposes owing to their electrostatic dust attraction and trapping properties (CROSS, 1987; TAYLOR and SECKER 1994; HILCZER and MALECKI, 1986).

The dust anchoring ability of commercially available polypropylene (PP) electret fibre material was investigated to determine whether, in appropriate applications, it could be used to effect substantial control of dust in general and, specifically, Der p 1 allergen carrying particles. The electret fibres were compared to identical uncharged (or non-electret) PP fibres as well as wool and nylon fibres. Wool, nylon and PP are all common domestic textile materials.

2 Materials and methods

Polypropylene electret (E), heat-treated electret (HTE) and non-electret (NE), and wool and nylon fibres were soiled with sieved house dust and vacuumed for 120 s at three calculated air face velocities. The degree of soiling was initially very high to determine whether useful anchoring effects in the electret can be observed under challenging conditions. The degree of soiling was serially lessened to ascertain the effect of soil loading. The air flow over the fibres and dust created

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forces that acted to separate the dust from the fibres. Dust removed by vacuuming was collected on filter paper. The concentration of Der p 1 allergen in the collected dust, measured in μg of allergen per g of collected dust ($\mu\text{g/g}$), was determined by monoclonal antibody Enzyme Linked Immuno-Sorbent Assay (ELISA)*. Some tests were analysed for particle size distribution characteristics.

2.1 Test fibres

All PP fibres used during experimentation were either Filtrete™ E fibres† or uncharged NE fibres from the same source. None of the PP fibres had been treated by any form of anti-static agent. The effect of reduced electric charge in the electret through heat-induced charge relaxation was also tested. Charge relaxation (or leakage) of electret polymers occurs whenever the electret is heated beyond a threshold temperature that is a characteristic of the polymer (HILCZER and MALECKI, 1986). Charge relaxation was accomplished by heat treating the E fibres at $125 \pm 5^\circ\text{C}$ for 15 min.

The wool fibres were blended best English cross‡, as used in carpet manufacture, and the nylon fibres were standard non-antistatic nylon 6**, also used in carpet manufacture. All fibres were supplied in a homogenous density and random orientation or 'fleece' form.

2.2 Test dust

House dust was collected from three households by conventional vacuuming of carpeting, soft furnishings and bedding. Raw dust from the vacuum cleaner bags was serially sieved to less than 63 μm to produce dust with a higher Der p 1 concentration and to isolate dust anchoring effects to the particle size region of interest. All the sieved dust was mixed thoroughly to achieve uniform particle distribution. Sterility against dust mites was ensured by freezing at -20°C .

2.3 Experimental set-up

The PP fibre fleeces were divided into 0.20 ± 0.005 g samples. To achieve consistent fibre density per unit volume, the nylon and wool fibre fleeces were divided into 0.30 ± 0.005 g samples. Each sample was formed by hand to fit uniformly into a 72 mm diameter cylindrical receptacle, as illustrated in Fig. 1. It was determined, by the use of a Faraday cup and electrometer measurement system (CROSS, 1987), that the handling of the fibres did not result in significant amounts of net electrostatic charge on the fibres. The samples were sandwiched between two wire mesh discs and weighed. The upper disc was constructed with a coarse mesh and acted as a structural element to maintain the fibre sample shape. The lower disc was constructed with a fine mesh and again acted as a structural element to maintain the fibre sample shape. In addition, the lower mesh allowed the easy passage of dust, but not the fibres, under vacuuming conditions.

The test fibre sample and mesh disc sandwich was then soiled topically with 0.20 ± 0.005 g of sieved dust. The sandwich was subsequently agitated until the dust was completely encompassed by fibres and weighed again. The sandwich was then placed in the cylindrical receptacle.

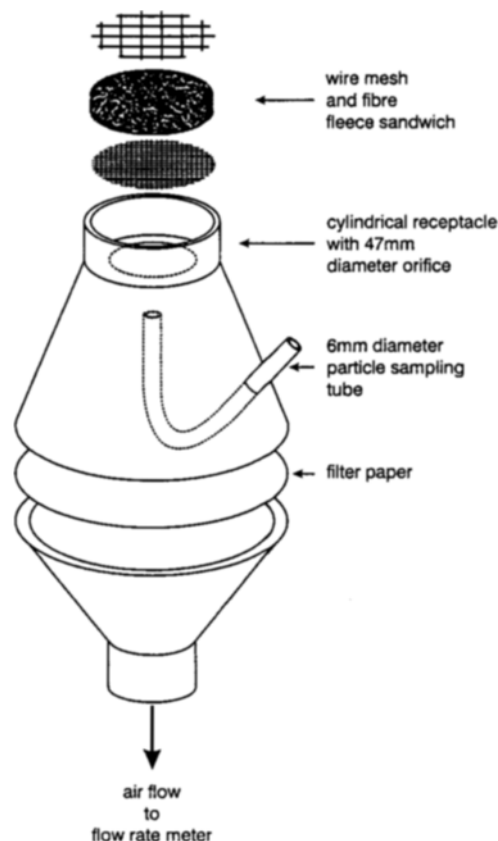


Fig. 1 Exploded view of the experimental set-up

The base of the cylindrical receptacle had a centrally situated 47 mm diameter orifice. This orifice connected the receptacle to a filter unit that collected the dust removed from the test fibre samples under vacuuming conditions onto filter paper. The dust collected was weighed and then used for the ELISA. To avoid cross-contamination of collected dust samples, the cylindrical receptacle and filter unit were cleaned after each individual test. A 6 mm diameter copper collection tube in the filter unit was connected to an air particle counter** that determined particle size and distribution in eight channels between 0.3 to 25 μm .

Vacuuming strength was determined by calculating the intake air face velocity. This was accomplished by placing an air flow rate meter* in the vacuum tube after the filter unit. The approximate air face velocity could then be calculated by dividing the flow rate by the cylindrical receptacle orifice area. Although the air face velocity is less than the air velocity distribution that would be experienced by the test fibres, it provides a measurable parameter that can be used to standardise the experiment. Immediately after vacuuming, the fibre and mesh samples were weighed for a third time. The weighing information was used to calculate the amount of dust added to and remaining in the test fibres.

Twenty samples were tested in determining overall dust anchoring, and Der p 1 allergen concentration characteristics were obtained for each of the five fibre conditions and three air face velocities. Five samples for each of the five fibre conditions and three air face velocities were tested for particle size distribution.

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** Malvern, UK, model no. APC 300 A

* Airflow, UK, model no. AV-2

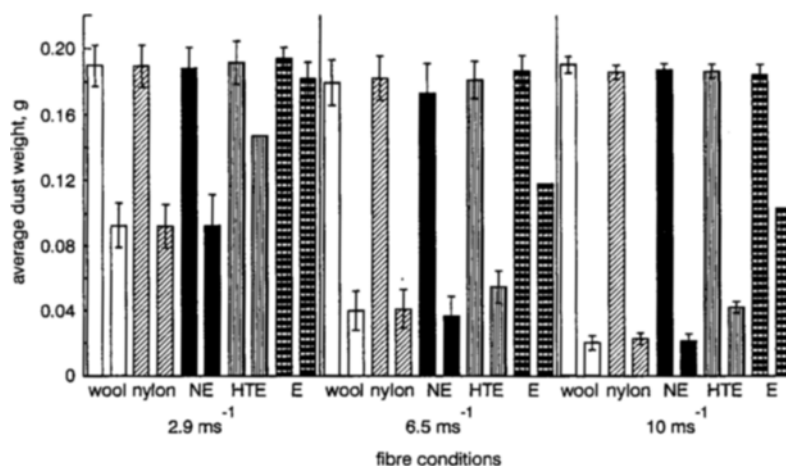


Fig. 2 Average dust weight in fibre samples before and after vacuuming at the calculated air face velocities for 120 s (error bars indicate 95% CI)

3 Results

3.1 Dust anchoring

Fig. 2 shows the average weight of sieved dust added before and remaining after vacuuming at the three calculated air face velocities of 2.9, 6.5 and 10 ms^{-1} , for the three different PP fibre conditions, wool and nylon. The calculated air face velocity of 6.5 ms^{-1} is very close to that at the cleaning head of a commercial vacuum cleaner† (using manufacturers recommendations for vacuuming carpets). It is apparent that the dust anchoring ability of the E fibres is significantly better than either the NE, nylon, wool or HTE fibres. The error bars show the 95% confidence interval for a normal distribution. It is also apparent that the HTE fibres have retained at least some of their charge owing to their slightly better dust anchoring performance compared to the NE fibres. The difference in the amount of dust remaining anchored is shown to increase with increasing air velocity.

The initial degree of soiling for the PP fibres was very close to a 1:1 fibre weight to dust weight ratio, and for the other fibres a 1.5:1 ratio. This is an unrealistically high level of soiling. Soiling levels were serially reduced by reducing the amount of added dust to ratios of 2:1, 4:1 and 8:1 to ascertain the effect of dust loading. Fig. 3 shows the percent of dust remaining for NE and E fibres at a calculated air face velocity of 6.5 ms^{-1} for the soiling ratios stated previously. As the level of soiling drops, the percentage of dust remaining anchored increases in the E fibres but remains relatively constant in the NE fibres. At the lowest soiling level the E fibres anchor about 5.6 times more dust than the NE fibres, compared to 3.1 times more dust at the highest soiling levels.

Tests were conducted in an uncontrolled humidity environment. Relative humidity was measured to have an average of 50% with a standard deviation of 10% (range 32–86%). This variation in humidity produced no observable effects on dust anchoring ability.

The amount of dust remaining in the fibre fleeces is a good indication of the saturation level for the test fleeces at the given air face velocities. Further vacuuming of samples for 240, 360 and 480 s yielded almost identical dust retention values. Thus, at the highest air face velocity tested and the highest soiling level, the E fibre fleece has a saturation level about 5 times larger than either the wool, nylon or NE fibre fleeces.

3.2 Particle size distribution

Particle numbers in each of the eight channels were added to ascertain the total number of particles counted in an individual test. The percentage of total particles for each channel was then calculated and averaged over the five samples. To indicate differences in particle size distribution between the fibre conditions relative to the E fibres, the averaged percentage data was normalised to E fibre values. The normalised distribution for an air face velocity of 6.5 ms^{-1} is shown in Fig. 4. Values less than one indicate a lower relative percentage of particle release for that size channel compared to E fibres. Inversely, values greater than one indicate a higher relative percentage of particle release compared to E fibres. The error is shown for a confidence interval of 68%. The general trend shown in Fig. 4 is maintained for the calculated air face velocities of 2.9 and 10 ms^{-1} .

3.3 Dust Der p 1 allergen

Dust collected from each of the 20 replicates for all the fibre types and calculated air face velocities was stored in a single container for each experimental condition. This effectively averages the allergen concentration for the 20 replicates. Samples of 0.5 g from each of these containers were then used for Der p 1 extraction and dilution for the ELISA tests. The results are shown in Table 1. No significant difference in allergen concentration of collected dust,

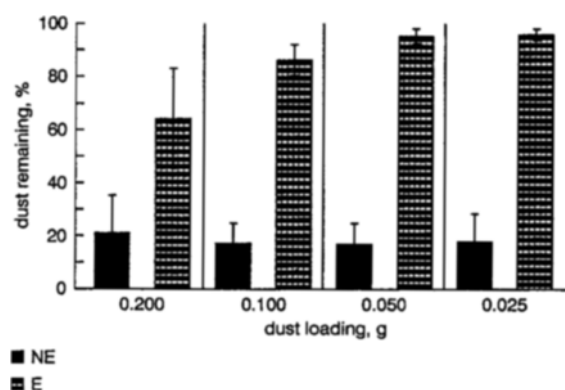


Fig. 3 Percentage of dust remaining in NE and E fibres for dust loading of 0.200 g, 0.100 g, 0.050 g and 0.025 g after vacuuming for 120 s at a calculated air face velocity of 6.5 ms^{-1}

† AEG Vampire 2000, AEG, Germany

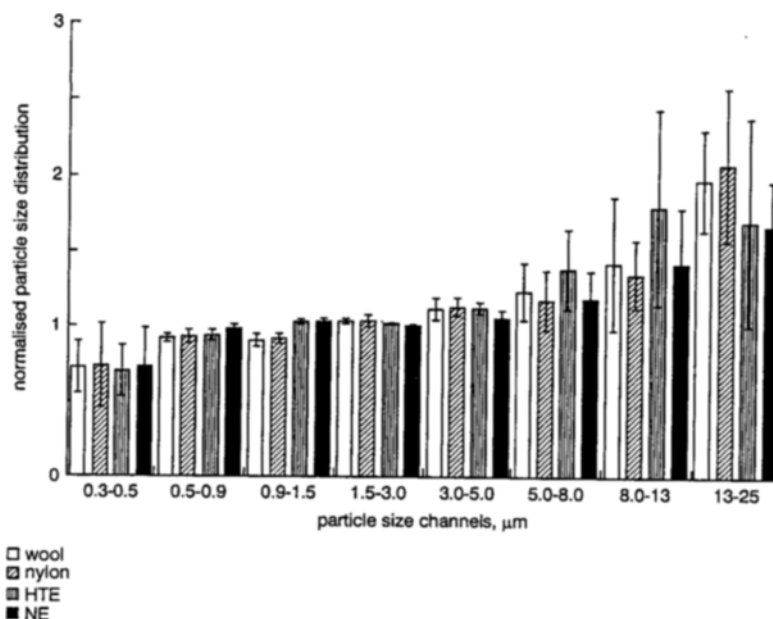


Fig. 4 Normalised particle size distribution of dust removed from the test fibres, over eight channels, relative to E fibre values for a calculated air face velocity of 6.5 ms^{-1}

Table 1 Der p 1 allergen concentration derived from monoclonal antibody ELISA from stock dust, C, and all the fibre types at the three calculated air face velocities (CAFV)

CAFV, ms^{-1}	Der p 1 allergen concentration ($\mu\text{g/g}$)			
	NE, nylon, wool	HTE	E	C
2.9	2.8 ± 1.3	2.7 ± 1.0	$31. \pm 1.0$	NA
6.5	3.0 ± 1.2	2.7 ± 1.0	3.0 ± 0.9	2.9 ± 0.9
10	2.7 ± 1.1	3.1 ± 0.9	2.9 ± 0.9	NA

between the five fibre conditions and the three air face velocities, could be ascertained. In addition, there was no significant difference in measured allergen concentration of collected dust relative to the initial sieved stock dust used in the experiments. ELISA tests were not performed on the dust collected from the lower soiling level experiments as insufficient amounts were obtained to provide accurate dilution data.

4 Discussion

The E fibres tested showed significantly different dust anchoring characteristics relative to dimensionally identical NE fibres. At the lowest calculated air face velocity of 2.9 ms^{-1} and highest level of soiling, about 95% more dust remained anchored in the E fibres than in the NE fibres. At the highest air face velocity of 10 ms^{-1} and also the highest level of soiling, about 370% more dust remained anchored in the E fibres. This consistency of effect is important when considering the variation in possible forces that could remove particles from the fibres. The difference in anchoring effect is also consistent when compared to uncharged wool and nylon fibres.

Der p 1 allergen carrying particles in the test dust appear to be neither specifically attracted to or repelled from the PP fibres, irrespective of fibre charge content. If the allergen was specifically attracted to the electret fibres, a corresponding drop in allergen concentration in the collected dust would be expected. Alternatively, if the allergen containing particles

were repelled by the electret fibres, an increase in allergen concentration in the collected dust would be expected. The insignificant variations in allergen concentrations of collected and initial dust determined by ELISA could not show any selective characteristics. Therefore, the reduction in the amount of dust released from the E fibres compared to the other fibres is directly proportional to the reduction in the amount of Der p 1 allergen carrying particles released. In the experimental tests, the E fibres thus reduced the overall amount of Der p 1 allergen released by 49% at 10 ms^{-1} calculated air face velocity, 54% at 6.5 ms^{-1} and 88% at 2.9 ms^{-1} , compared to NE fibres at the highest levels of soiling.

The high degree of initial soiling, well beyond the saturation levels of the fibre fleeces, reduces the difference in effect between the fibre conditions. Reduction of the amount of soiling to more realistic levels increased the observed differences by a factor of about 10. Thus, at a fibre to dust weight ratio of 4:1 (which is still a relatively high degree of soiling) and a calculated air face velocity of 6.5 ms^{-1} , the amount of Der p 1 released from the E fibres is 94% less than that released from the NE fibres. Whatever the dust control application that may use electret fibres, soiling of the fibres over time will reduce the electrostatic anchoring effect. However, if the fibres are kept relatively clean by some form of maintenance, this problem can be remedied. The maintenance must provide the ability to remove the same amount of dust or more from a surface or area that would normally be achieved without the presence of electret material, otherwise there is a potential for the higher level of remaining dust to become airborne under some conditions.

Electret material that becomes saturated with trapped dust could possibly be cleaned by conventional domestic wet washing without necessarily affecting the electret material. Care must be taken when using surfactants and fabric coating products during washing, as residues of these chemicals on the fibres may reduce dust attraction and anchoring ability (GAYNOR and HUGHES, unpublished data). It is also possible that some electret charge may be neutralised by free electric charge carriers in water. It has been shown that higher temperature water based cleaning of items such as bedding, soft toys, clothing and carpets can significantly reduce HDM

allergens and populations (ANDERSON and ROESEN, 1989; McDONALD and TOVEY, 1992; COLLOFF *et al.*, 1995; WASSENAAR, 1988), although transient high moisture levels must be made as short in time as possible to avoid favourable HDM growth conditions.

The preliminary investigations into particle size distribution of the test dust indicate that although there appears to be little difference in Der p 1 concentration in the collected dust over the five fibre and three air face velocity conditions, there does appear to be possible differences in particle size distribution. However, between about 0.5 µm to 5 µm, the particle size distribution percentages seem to be relatively similar throughout the test conditions. If Der p 1 allergen is predominantly present in those particle size ranges, then Der p 1 concentrations would appear to remain constant. Although faecal particles found in the domestic environment are normally larger than about 10 µm (PLATTS-MILLS *et al.*, 1986; TOVEY *et al.*, 1981), the considerable physical agitation of the test dust by initial collection and serial sieving may have caused some disintegration of the faecal matter into smaller particles. Also, Der p 1 may be present in fragmented HDM remains or have leached onto other particles that could be smaller than 10 µm. It remains to be shown whether fresh or intact faecal particles are selectively attracted to or repelled from E fibres. The particle size distribution results do suggest, however, that the E fibres may cause a reduction in Der p 1 concentration if the whole faecal particles are selectively anchored as other particles in their size range appear to be. This effect would be in addition to the observed overall reduction of allergens and dust in general.

The negative effect of partial charge relaxation was shown in the results for the HTE. Therefore, any allergen avoidance product incorporating electret material requires a consideration of temperature during manufacture. Temperatures experienced by the electret material during its functional lifetime must also be considered.

It has been indicated that the maximum peak intake air flow rate of an infant under 110 cm tall is about 75 l min⁻¹ (FORFAR and ARNIEL, 1984). This equates to an air face velocity of about 10 ms⁻¹ at the nose and about 2 ms⁻¹ at the mouth. An infant under 12 months old is capable of only about a tenth of that velocity. At these levels, the amount of dust inhaled by an infant whose face is in contact with, or close to, a material containing significant levels of dust could be considerably reduced if that material contained electret fibres.

Adherence to electrostatic charging and dissipation standards is likely to be maintained when using electret material. The polypropylene electret fibres match natural polypropylene fibre properties, apart from the trapped net charge. Since the charge is trapped it cannot be easily transferred to any other material thus cannot contribute to natural tribo(frictional)-electric charging.

High-efficiency vacuum cleaners have been shown to produce significantly less aeroallergens during vacuuming, compared to standard vacuum cleaners (HEGARTY *et al.*, 1995). Although this is an extremely important aspect of allergen avoidance, it does not affect the ability of the carpet to release allergens left behind after vacuuming, through mechanical disturbance. Even high-efficiency vacuum cleaners will leave behind significant amounts of dust under normal conditions. Thus, materials that keep the remaining dust anchored to the surface until it can be removed by an appropriate cleaning method offer a major advantage in allergen control. It has been suggested that this type of effect was observed in synthetic fibre carpeting that was proposed to have a higher electrostatic charge than wool

fibre carpets (PRICE *et al.*, 1990). However, owing to the newer generations of antistatic synthetic carpet fibres, significant electrostatic charging levels are limited to older synthetic carpets. Also, the amount of electrostatic charge generated in materials by friction with other materials (known as tribo-electric charging) is extremely variable depending on environmental and physical parameters (CROSS, 1987). The authors are currently investigating the possibility of incorporating PP electret fibres into carpets in order to achieve reduced aero-allergen levels from that source. It has been found that, depending on where the electret fibres are located in a carpet, airborne levels of dust can be substantially reduced during mechanical agitation and yet overall dust removal during vacuuming can be enhanced (GAYNOR and HUGHES, unpublished data).

Electret polymer fibres appear to be ideally suited for use as stuffing material in products that are known to harbour dust mites and can be easily washed and dried, such as pillows, soft toys and some furnishings. Other easily washable domestic textiles, including clothing and curtains, also seem to be suited to this sort of allergen control. However, this depends on the ability of the electret material to retain its dust anchoring properties after multiple exposure to washing conditions. Owing to the physical nature of the electrostatic particle adhesion properties of electrets, control of other particulate allergens could be expected. In addition, it is economically viable to consider the use of electrets owing to their generally low cost.

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